CHAPTER D.6
RESTORATION TOOLS FOR LOUISIANA'S GULF SHORELINE

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6.1 Summary

A range of tools can be employed to restore Louisiana's barrier islands. These tools include models that predict the response of barrier islands to natural forces (waves, tides, wind, sea level rise); beach nourishment programs that rebuild islands; the use of "hard" structures, such as breakwaters and jetties; and vegetative plantings. Each of these tools is described in detail below.

6.2 Applications and Uses of Coastal Models

6.2.1 Introduction

This section discusses the information that coastal models can provide, as well as the limitations of these models. A "one size fits all" approach will not generate useful data. Instead, each model must be customized to the geographic area under study. In addition, models must be designed to accommodate rare natural events, such as severe storms.

Barrier islands are dynamic features that change in shape (length, width, height, planform), geographic position, and orientation in response to waves, relative sea-level rise, sediment supply, and to a lesser degree winds and currents. The Louisiana barrier islands show extreme manifestations of these processes with extraordinary retreat rates and subaerial acreage losses over the last 100 years. As we consider the applicability of coastal models, it is critical to appreciate, that the scale of physical changes in Louisiana is an order of magnitude greater than what has been experienced in most barrier islands for which existing models have been developed. It is probable therefore that existing shoreline and cross-shore models will require modifications before they can be used to predict barrier island evolution in Louisiana. In order to improve quantitative understanding of the coastal processes, a basic conceptual-analytical model should be developed. This model should describe the coastal process and sediment transport that affect barrier islands and headlands. An important component of the conceptual-analytical model should be a three-dimensional littoral budget that tracks (i.e. quantifies) the movement and relative conservation of sand and fine sediment (silt and clay) in the system.

Coastal scientists and engineers have developed numerical models to help predict waves, water-level, shoreline positions, volumetric changes, and fluid dynamics. Wave models may have to be modified to adequately consider wave decay in response to bottom friction and mud entrainment. Shoreline change and cross-shore models should not be directly applied to Louisiana barrier islands until the mechanisms that force their extraordinarily dynamic behavior can be explained in analytical and quantitative terms. Calibration issues and assumptions tied to existing models need to be fully appreciated to allow for proper model application. Shoreline and cross-shore models developed for sandy coasts will require modifications when used for the Louisiana coast where fine sediments (e.g. silt and clay) play a significant role in profile and shoreline response. Wave modeling to analyze the effects of discrete bathymetric changes such as borrow areas should properly consider multi-spectral rather than monochromatic waves. Compared to individual wave analysis, natural wave spectra reveal less total refraction and shoaling, as well as less amplification and faster decay of wave heights due to interactions between different wave types.

This chapter examines available model types, including their capabilities and limitations, and discusses some sediment and structure applications (“soft” and “hard” coastal protection approaches) commonly used in coastal engineering industry. The use of existing models that may be adaptable to the conditions in Louisiana are discussed. This chapter also proposes the development of a site-specific conceptual model that will apply the quantitative tools needed for implementing an adaptive management approach.

6.2.2 Analytic Desktop Models

Although the basic causes of shoreline retreat and acreage loss are identified (e.g. land subsidence and sediment starvation), the process-response mechanisms that force island retreat and shoreline change require proper identification within a quantitative framework. It is important to develop a basic understanding of how the magnitudes of sediment movements and relative sea-level rise (RSLR) produce documented changes in headlands and barrier islands.

Because retreat rates of 10-60 ft/yr (3 to 20 m/yr) along Louisiana’s shoreline exceed rates that are observed elsewhere, a unique combination of factors must be at work. In order to understand these physical changes, an analytical model that deals with measured rates of retreat should be developed. The model would be based on current knowledge and subsequently enhanced, as restoration project monitoring and adaptive management proceed.

A comprehensive littoral budget for each coastal segment will be the first step towards the development of such a model. The sediment budget would include estimated losses and gains of sand and fine sediment (silt and clay) cross-shore, alongshore, and across cell boundaries. Measurement of changes in the position and volume of sand and fine sediment (silt and clay) in the system would then refine the model estimates. A conceptual diagram summarizing some of the process that should be considered within the proposed model is presented in Figure D.6- 1.

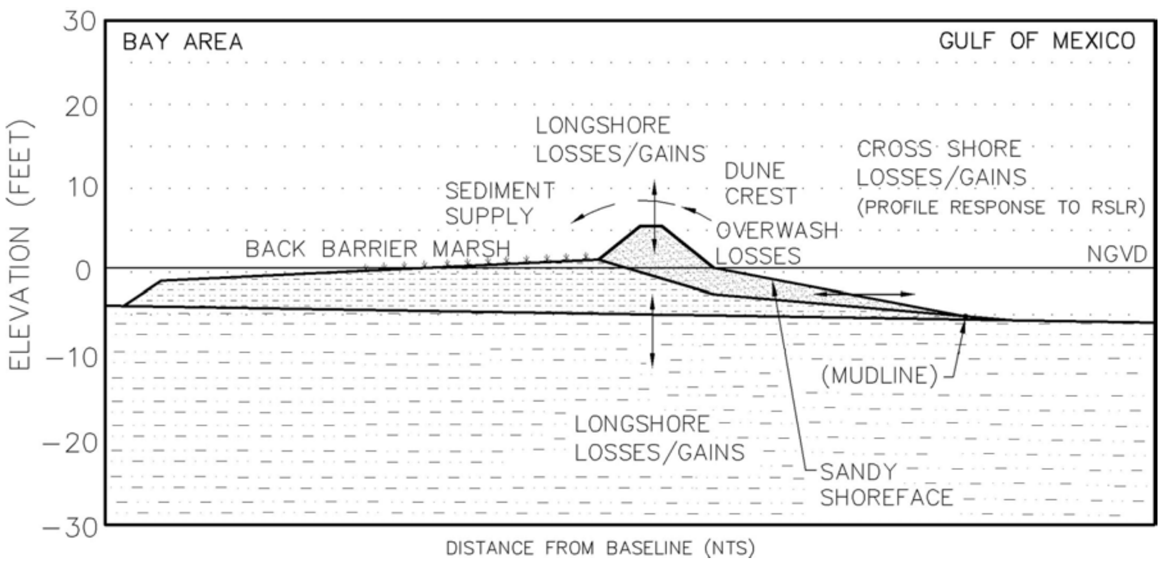


Figure D.6- 1. Sketch diagram illustrating conceptual model approach.

6.2.3 Existing Analytical and Numerical Shoreline Change Models

Pioneering work related to shoreline change models began in the 1950s when Pelnard-Considere first approximated a mathematical model and compared the solution of shoreline change at a groin with laboratory experiments (Capobianco et al. 2002). Since these early efforts, the general approach of shoreline change models involves the simulation of long-term shoreline change (e.g. “long-term erosion models”) on an open coast as produced by inputs related to the spatial and temporal differences in longshore sand transport (Hanson and Kraus 1989). Numerical shoreline change models involve division of the shoreline into individual cells. Equations relating longshore sediment transport as a function of wave action and longshore currents are used to estimate movement of sand from one cell to another. Application of the continuity equation makes it possible to estimate shoreline changes by the conversion of sediment volumes entering and exiting each cell.

Shoreline change governing equations are usually expressed in the form of (Kraus and Gravens 1991) (Figure D.6- 2):

$$\partial y/\partial t+1/(D_b+D_{oc})*(\partial Q/\partial x-q) =0 \qquad \text{Eq. 1}$$

In order to model shoreline change (∂y), other terms in the equation (as illustrated in Figure D.6- 2) must be known or accurately estimated. These terms are: Q (longshore transport rates), q (sources and sinks of sediments), D_b (berm height) and D_{oc} (depth of closure). Shoreline models predict changes that are induced by gradients in longshore transport only. Other system components that are responsible for observed shoreline changes (e.g. cross-shore) must be considered separately, with additional methods.

A common practice among coastal engineers and scientists is to use known values of shoreline change (∂y) over a known period of time (∂t) to infer transport rates ∂Q and/or sources and sinks. For this approach to be valid, it is assumed that all shoreline change observed through time is a function of alongshore variations of transport rates and/or sediment supply deficits or surplus.

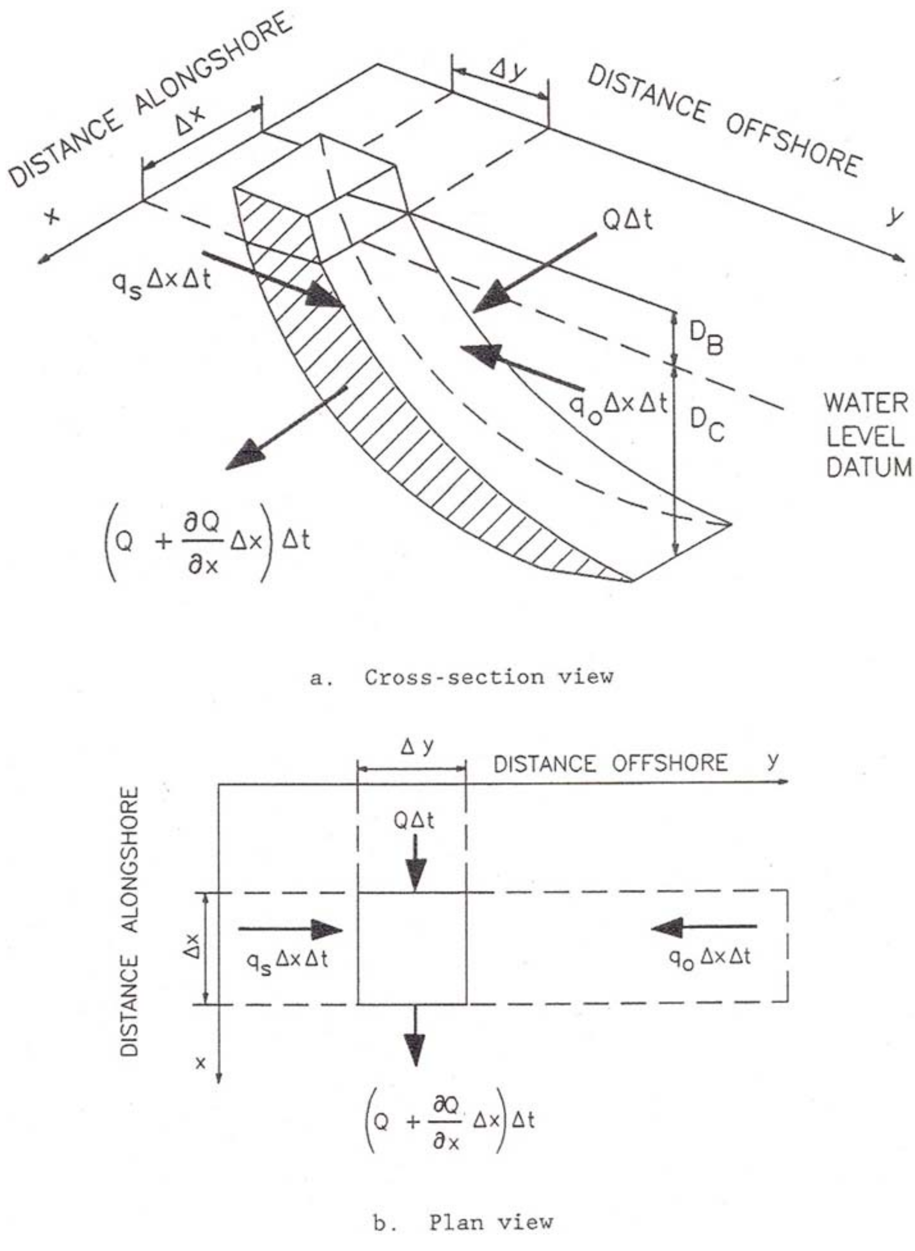


Figure D.6- 2. Cross sectional definition sketch of parameters used for shoreline change calculation (after Kraus and Gravens 1991).

The fundamental assumption of shoreline modeling is that the beach profile moves landward and seaward while retaining the same cross-shore shape. Therefore, any point on the profile is sufficient to specify the horizontal location of the profile in relation to a baseline, and one contour line can be used to describe beach plan shape and volume as the beach erodes or accretes (Gravens and Kraus 1991). These shoreline models are thus termed “one line models.”

A second geometrical assumption is that sediment is transported alongshore between two pre-defined limiting elevations on the profile. The shoreward limit is located on the top of the active berm or dune, whereas the seaward limit is located at depth of closure (Doc, defined as the depth where no significant depth changes occur, Figure D.6- 2).

Restrictions of profile movement between these two pre-established limits are necessary to relate volume change per unit distance with beach shoreline advancement or retreat. Several mathematical methods have been proposed to estimate depth of closure for sands (e.g. Hallermeier 1981; Nichols and Birkemeier 1997). Recently CPE found a Doc for sand in the Chenier Coast at -4 ft (NAVD 88). This sand depth of closure was the offshore position where sand sized sediments transitioned to silt.

Shoreline change models also require a predictive expression for the net longshore transport rate. On open coast beaches, where most of the models were developed (e.g. Hanson and Kraus 1989), the transport rate is a function of breaker wave height and direction alongshore.

Situations that are not suitable for the application of shoreline change models include, according to Gravens et al. (1991) and Hanson and Kraus (1989): beach changes inside inlet systems, beach changes produced by wind driven currents, and conditions characterized by a dominant cross-shore sediment transport process. Shoreline models are not effective for a number of Louisiana barrier islands that are rapidly retreating due to cross shore processes (e.g. overwash, profile response to sea-level rise).

Current shoreline change models may have limited applications for Louisiana’s delta shoreline:

(A) The models are calibrated and verified by measured shoreline changes. In Louisiana, most shoreline changes are driven by cross-shore process that, in turn, are forced by submergence and fueled by major storms. These cross-shore changes need to be filtered out of the shoreline change data to accurately produce reasonable results. Thus it would not be appropriate to calibrate a shoreline model in Louisiana based on measured shoreline changes as is typically done with these models.

(B) The presence of fine sediment (silt and clay) and sand in the cross-shore profile requires tracking sand (inshore) to obtain quantities that are usable for ecosystem restoration purposes.

(C) The conservation of volume required by modeling might be violated for the fine fraction (e.g. silts and clay), which will be suspended in the water column and transported beyond the sand closure depth.

(D) Transport of cohesive sediments is not incorporated in the existing transport equations used by the models.

Because of the limitations associated with specific conditions along the Louisiana coast, shoreline change models should be cautiously applied in Louisiana and the results critically reviewed. One way to potentially deal with the problems listed in “B,” “C,” and “D” is to run the models for sand closure using the D_{oc}-s that is measured on the shoreface transition or boundary between silt and sand. Problem "A" will, however, persist.

If shoreline modeling is attempted in Louisiana, models should be calibrated using volume changes (rather than shoreline changes) measured in accurate topographic and bathymetric surveys on emergent and submergent portions of the islands. When this procedure is not possible, other sources of measurable sediment sources and sinks should be sought (viz. ebb tidal deltas, spits, and overwash platforms as shown in Figure D.6- 3). These features should be sampled, cored, and surveyed to determine sand budgets in order to enable proper model application.

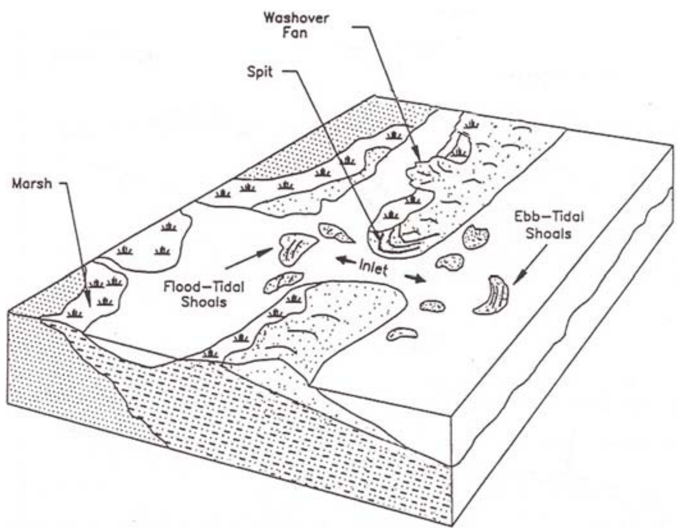


Figure D.6- 3. Examples of a few measurable geomorphological indicators of sediment sources and sinks that occur in Louisiana barrier island systems.

6.2.4 Cross-Shore Profile Evolution Models

Another category of models commonly used to simulate barrier island response to hydrodynamic forcing was developed to calculate cross-shore processes and cross-shore profile responses to storms ("storm-models"). Cross-shore models were previously developed for both emergent (e.g. Kriebel and Dean 1985) and submergent parts of the profile (e.g. Larson and Kraus 1989). Due to the complexity and randomness of nearshore sedimentary processes, most profile evolution models are based on empirical relationships. These relationships are derived from controlled laboratory tank experiments and verified with field experiments (e.g. Larson and Kraus 1989; Larson et al. 1990). In these models, the profile is divided into cells where a cross-shore transport equation describes sediment changes across the profile, and a continuity equation integrates differences between sediment input and output to each cell. The continuity equation then equates these differences to changes in profile elevation.

Profile change models have been used on sandy coasts to evaluate immediate beach response to storm conditions and to evaluate the initial equilibrium response phase of a newly created beach fill on sandy beaches. It is not known, however, whether these cross-shore models can be applied to the Louisiana mixed fine sediment (silt and clay) environment. Rosati et al. (1993) emphasize that SBEACH is an empirically based model that was originally developed for sandy beaches with uniform representative grain sizes in the range of 0.20 to 0.42 mm. Although it may produce reasonable results for beaches beyond these limits, there is no general agreement as to whether it can successfully predict storm induced changes for profiles dominated by the very fine sand and silts and clays found offshore of Louisiana barrier islands. The physics governing the profile responses of fine sediment (silt and clay) is very different from processes in sandy bottoms, and fine sediment recovery is much slower and many times not fully achieved (Mehta 2002).

A fundamental assumption of profile change models is that breaking waves are the major cause of profile change. The direction of transport is given by an empirical predictive criterion (Larson and Kraus 1989) that incorporates incident wave and grain size characteristics (Eq. 2).

$$H_o/L_o = M(H_o/W_sT)^3 \qquad \text{Eq. 2}$$

where H_o is the deepwater wave height, L_o is the deepwater wave length, M is an empirically determined coefficient, W_s is the sediment fall velocity, and T is the wave period. The left term of the equation is the so-called deepwater wave steepness. The right term (H_o/W_sT) was originally derived by Gourlay (1968), but is now popularly known as the Dean Number (Dean 1973). Wright and Short (1984) also replaced H_o for H_b (deepwater wave for shallow water breaker height) in the dimensionless fall velocity parameter ($H_b/W_s{*}T$) and successfully classified beaches into six distinct morphodynamic states. The authors stated that when the parameter increases, the dominant transport is offshore and vice-versa. In the approach of Larson and Kraus (1989), Eq. 2 dictates transport direction such that the net transport direction is offshore if the left term is smaller than the right term, and onshore if the left term is greater than the right term.

Because profile change models are two-dimensional, longshore transport is omitted. These models should only be applied, therefore, if longshore gradients in transport process can be neglected (Rosati et al. 1993), or are well known and quantified in a separate analysis using different methods/models. The models should not be used to examine profile change downdrift of jetties or groins (that block longshore transport and induce a bias to the system). Nor should they be used for long-term analysis of cross-shore transport processes where forces other than breaking waves and water levels may contribute to profile changes (e.g. subsidence) (Larson et al. 1990).

6.3 Basic Concepts of Shoreline and Profile Modeling

6.3.1 Closure Depth

The depth of closure (D_{oc}) is widely used by coastal engineers to establish sand budgets, design beach nourishment projects, and define boundaries for coastal models. The concept, which defines the seaward limit of the active profile, is based on the assumption that it is possible to distinguish a depth value that divides the active profile (a zone that constantly changes as the beach interacts with incident waves) from a deeper zone where all net morphological changes are negligible (e.g. Hallermeier 1981; Nichols et al. 1996). It is possible to derive a reasonable depth of closure on sandy coasts from predictive equations that incorporate incident wave parameters (e.g. Hallermeier 1981; Nichols et al. 1996). A time-dependent version of the Hallermeier (1981) predictive equation is given by Nicholls, Hallermeier, and Birkemeier (1996) as:

$$D_{oc} = 1.75\, H_{e,t} - 57.9\, (H_{e,t}2/gT_{e,t}2) \qquad \text{Eq. 3.}$$

where D_{oc} is the predicted depth of closure over t years referenced to mean low water; $H_{e,t}$ is the non-breaking significant wave height that is exceeded 12 hours per t years, $T_{e,t}$ is the associated wave period, and g is the gravity acceleration. Eq. 3 provides a close first approximation for sand dominated environments to the true D_{oc}. Capobianco et al. (2002) emphasized, however, that there is a need to further develop existing formulas that incorporate additional parameters (such as sediment characteristics, profile slope) and adopt a probabilistic approach to the determination of D_{oc}.

For coasts with low wave energy regimes and a combination of sandy and fine sediments (silts and clays), such as those that occur along the Louisiana coast, it is helpful to differentiate between sand and silt depth of closure in order to properly define sediment needs. In Louisiana, relatively small, steep, sandy barrier island profiles are perched atop large, flat, fine sediment (silt and clay) profiles. Coastal engineering analysis of restoration projects in Louisiana (CPE 2000; CPE 2003) suggests a depth of closure shallower than what has been estimated in prior works. In this setting, the sand closure depth can be better defined using four alternative methods:

1.) Analyze surveyed profiles individually and identify the "break of slope," a distinctive interface between steeper sandy profiles at shallower depths, and flatter fine sediment-dominated profiles offshore. By reducing the alongshore variability in profile shape and perturbations of individual profiles, the use of "average profiles" is recommended. The average profile is determined by averaging multiple profiles within the study area to smooth out the perturbations of individual profiles. (e.g. Keehn and Pierro 2003).

2.) Analyze cross-shore distribution of sands and adopt the offshore sand closure depth (D_{oc}-s) as being equal to the offshore boundary between the finer sediments (silts and clays) and sand (this boundary is herein termed as the mudline).

3.) Calculate the theoretical equilibrium profile for the area based on composite beach grain size and identify the point of intersection between the calculated equilibrium profile and the measured profile.

4.) When using predictive relationships (e.g. Nicholls, Hallermeier, and Birkemeier 1996), include wave transformation across the wide and shallow shelf, and wave dissipation by fluidized sediments in the input parameters of the predictive equations.

Examples where one or more of these methods were applied to identify the closure depth along Louisiana's coastline include Holly Beach (CPE 2000) on the Chenier Plain and Chaland and Pelican Islands on the Plaquemines shoreline. On the Chenier Plain (Holly beach), cross-shore samples taken by CPE (2000) show that the beach is composed of fine sand to the 4 ft NGVD isobath; beyond that depth the sediments consist of silty sands to silt/clay (Figure D.6-

4). Since there is no sand movement deeper than four feet, it is reasonable to assume that this depth indicates the Doc-s for the area. This depth coincides with a pronounced break of slope in the offshore profile.

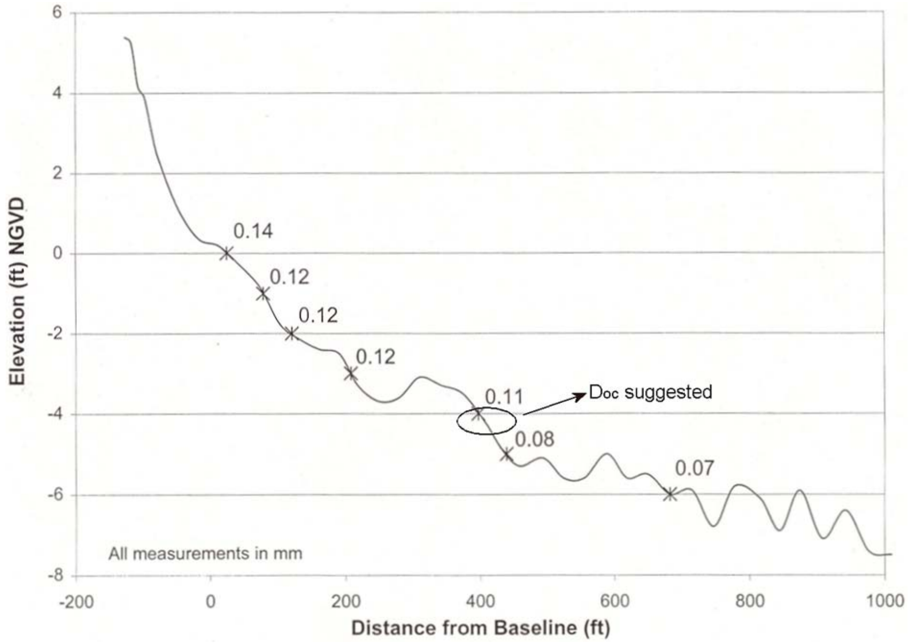
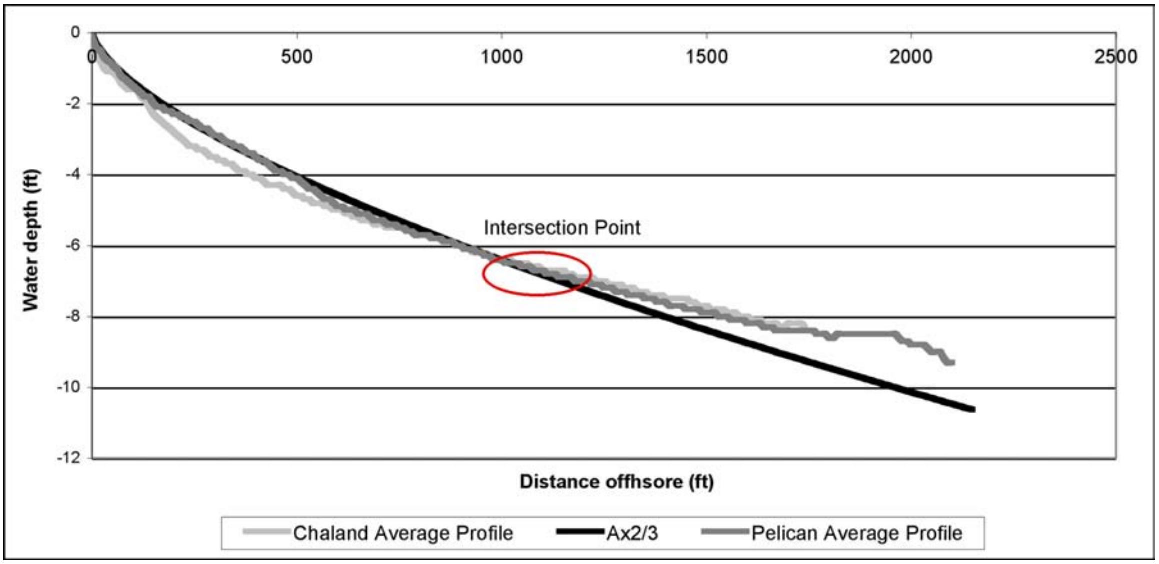


Figure D.6- 4. Example of measured Doc based on offshore sediment distribution and profile slope change at Holly Beach, Louisiana Chenier Plain.

Recently (CPE 2003) calculated the depth of closure for the sand portion of the profile using Eq.3, accounting for wave transformation across the wide shelf. CPE (2003) also verified that the depth obtained by this procedure (7 ft) coincided with the approximate sediment-line (silt/clay to sand offshore boundary) and the offshore break of slope of the measured profiles (Figure D.6- 4).

Average profiles were calculated for the 30 profiles at Pelican Island and 33 profiles at Chaland. Composite beach grain sizes (weighted averages of samples taken from the mid berm to - 10 ft) for these two beaches is 0.11 mm. It was found that the Dean Equilibrium profile (see next section) for 0.11 mm sand intersects the measured profiles at the same approximate water depth (6 to 7 ft; Figure D.6- 5), indicating converging lines of evidence to support the shallower sand Doc-s proposed.



Note that at approximately 7 ft depth, the equilibrium profile diverges from the measured profiles. The circled area indicates the closure depth for these profiles. This value coincides with the sandy-silt interface measured by CPE (2003) and with the calculated Doc calculated using Hallermier's equation accounting for wave decay across the shelf.

Figure D.6- 5. Average profiles for Chaland Pass to Pass de la Mer and Pelican Island, Plaquemines shoreline, Louisiana.

A discrete fine sediment depth of closure ($D_{oc\text{-}m}$) may not exist because significant quantities of fine sediments may move to very deep water and not return to the active profile. However, recent work by Mehta (2002) and Kirby (2002) suggest an equilibrium profile for fine sediment coasts with an effective depth of closure, which may enable quantification of processes such as shoreline retreat caused by sea level rise. For initial coastal planning purposes in Louisiana, it is important to simply recognize the existence of a different depth of closure for fine sediment and sand without specific identification of the $D_{oc\text{-}m}$, since only the offshore sand portion of the barrier island profile and the marsh behind it are to be managed.

6.3.2 Equilibrium Profile

Many profile and shoreline change models and coastal engineering design practices are based on the concept that an equilibrium profile (EP) can be defined. According to Dean (1991), a quantitative understanding of the characteristics of equilibrium beach profiles is fundamental to the rational design of coastal engineering projects. The basic equation of the EP is given by:

$$h(y) = Ax^{2/3} \qquad \text{(Eq. 4)}$$

A plot of equilibrium profile curves for a grain size of 0.1 mm (A=0.063) and 0.2 mm is shown in Figure D.6- 6.

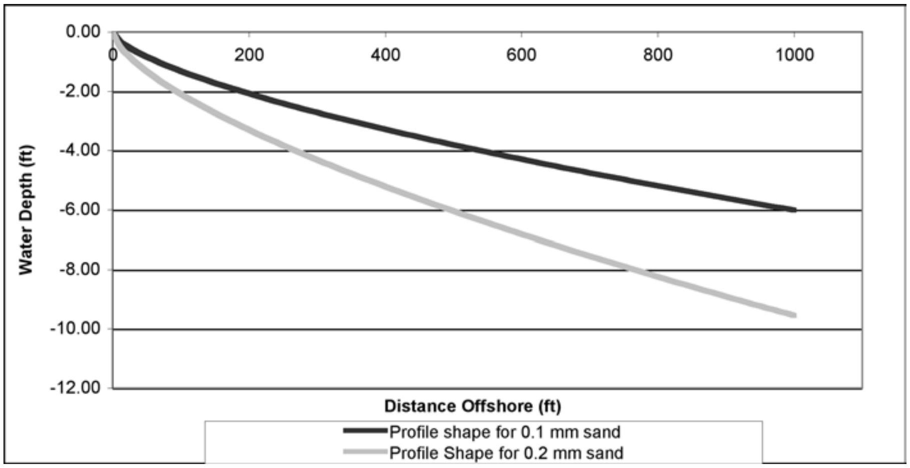


Figure D.6- 6. Equilibrium profile shapes for two hypothetical beaches containing fine sand (0.1 mm ('A'=0.063) and 0.2 mm ('A' = 0.100).

Generally the characteristics of equilibrium profiles (EP) as described by Dean (1977, 1991), are as follows:

- They tend to exhibit a concave upward shape.
- Smaller and larger sand diameters tend to produce milder and steeper slopes, respectively.
- The slopes tend to be flatter, and bars tend to develop for steeper waves.
- Sediments tend to be sorted across the shore, with finer and coarse sediments located in deep and shallow waters, respectively.
- The effects of change from perturbations that induce cross-shore transport can be estimated from these known characteristics.

The assumptions of the EP theory as originally derived (Dean 1977; 1991) include:

- Cross-shore process in a sandy shoreface are responsible for profile changes.
- The shoreface is sediment rich, and there is no control exerted by underlying hard-bottoms or fine sediments.
- Significant transport occurs between two pre-determined limits (Doc and berm height). The A factor, as given by Dean (2002), is a function of sediment fall velocity and empirical coefficients.

Even though some assumptions in EP theory limit the method, EPs are widely used for coastal engineering practices, and the concept provides a framework for quantifying “disequilibrium” from a known state. The coastal engineer or scientist who makes use of the concept should be aware of its limitations and should develop strategies to work with these limitations.

On shorefaces with composite grain sizes (e.g. silt-sand interactions on Louisiana barrier islands), there are two distinct equilibrium profiles: (1.) the equilibrium profile for the sand portion of the shoreface, which is steeper and will have a shallower seaward boundary (shallower Doc, greater A factor); and (2.) a deeper fine sediment equilibrium profile, which is convex for accretion areas, and concave with mild slope for eroding areas. As suggested by Mehta (2002) and Kirby (2002), these fine sediment-dominated profiles are associated with a much deeper depth of closure (Doc-m). The mud compartment will dominate seaward of the sand depth of closure (Figure D.6- 7). However for design purposes it is helpful to recognize the sand profile perched on the mud profile. Further development of design concepts in the report deals primarily with the behavior of the sand portion of the offshore profile.

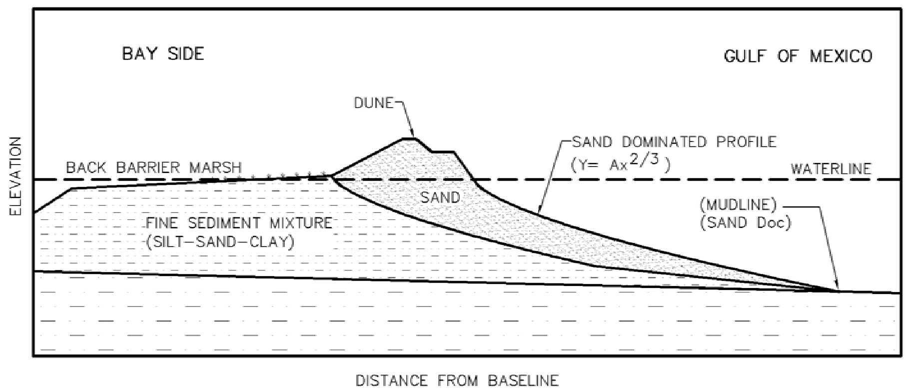


Figure D.6- 7. Hypothetical schematic drawing showing a sand barrier island. A distinction is made between the steeper sand portion of the profile and the flatter mud-dominated portion.

6.3.3 Wave Analysis

Because wind waves are important phenomena affecting the evolution of coastal landforms, it may help the planning process to develop a better understanding of wave generation, propagation, and attenuation in the nearshore gulf waters and bay systems of southern Louisiana.

Accurate wave information should help make the following analyses:

- determining the role that the barrier islands play in reducing wave energy that may impact back barrier marsh and bay shorelines
- evaluating potential structural solutions, such as terminal structures
- analyzing potential impacts of offshore dredging on wave climate and its potential impact on adjacent shorelines
- evaluating comparative littoral drift quantities and gradients to better define longshore volumetric losses

Data from a long-term network of gages is not available at sufficient duration or spatial resolution to meet long-term planning needs in this area. Consequently, it may be helpful to establish a reasonable baseline wave climate via numerical models. Such models utilize existing climatological wind fields to estimate directional wave spectra approaching the coast. When properly calibrated, validated, and applied, these models can provide estimates of processes affecting wave conditions and wave set-up in coastal areas. This is done as the waves transform from deep to shallow water and are re-generated behind islands and in inland water bodies.

6.3.4 Effect of Offshore Sand Removal on Coastal Wave Climate

In nature, wind-wave energy is distributed in terms of frequency, direction, and height. Wind waves are not well represented in terms of monochromatic, unidirectional wave trains. Instead, waves arriving at a particular point along a coast are actually the superposition (and often the nonlinear interaction) of a continuum of wave components. The total energy at a point is the summation of all of components in the directional wave spectrum, i.e.

$$E = \int_0^{2\pi}\int_0^{\infty} E(f,\theta)\,df\,d\theta \qquad \text{Eq. 5}$$

where $E(f,\theta)$ is the energy density in the wind wave spectrum at frequency f and direction θ. The directional spread of wave energy in locally generated wind waves is considerably broader than commonly realized. The "half-angle" of the directional distribution (the deviation from the mean angle within which one-half of all the wave energy is contained) ranges from about 20o to 30o for wind waves. This factor plus the natural spread of energy in frequency combine to reduce the effects of local perturbations in a wave field as the distance away from the perturbation increases. For example, the refraction pattern of one specific wave component (a single frequency and direction) behind a borrow pit in an offshore shoal can be complex and can contain very sharp gradients. Consequently, if one uses a monochromatic, unidirectional wave model, patterns of predicted wave effects behind shoals can be very large and persist for long distances. However, refraction patterns for natural waves (i.e. directional spectra with different frequencies and directions, consistent with waves found along the Louisiana coast) will have the locations of respective maximum focusing and maximum de-focusing displaced relative to each other, greatly diminishing both the local and non-local effects of sand removal shoals on leeward wave fields. A study by Vincent and Briggs (1989) showed that this effect was very striking, even for shoals that were specifically designed to focus waves behind them. In their study, a monochromatic, unidirectional wave focused to 2.8 times its incident height. By contrast, a directional spectrum typical of the Louisiana coast showed less than a 5% increase in wave height due to focusing, even immediately behind the shoal.

In addition to the decrease in local focusing, as one moves away from a borrow site, the size of the aperture covered by the half-angle increases linearly,

$$X = 2Y \tan(\phi) \qquad \text{Eq. 6}$$

where ϕ is the half-angle of the directional distribution, X is the aperture over which half of the wave energy is distributed, and Y is the distance behind the perturbation. For a half-angle of only 20 degrees, the aperture is approximately 0.73 times the distance that the point is removed from the perturbation. Over a distance equal to 10 times the perturbation size (roughly the extent of sand removal along a line perpendicular to the mean direction of wave propagation), the effect of the perturbation is limited to only a very small part of the directional spectrum arriving at a point, affecting less than about 1.5% of the total energy in the wave field. Thus, the maximum effect on the wave height is $1-(0.98)^{1/2} \approx 0.075$, which is less than a 1% effect on wave height. A similar argument shows that the effect of a borrow site on mean wave direction should be reduced by the distance between the borrow site and a point. A general rule of thumb for this reduction is that the effect of a local perturbation (shoal or borrow site) usually becomes negligible at a distance of about 10 times the size (length) of the perturbation. Interactions of spectral wave fields minimize wave focusing behind borrow areas.

6.3.5 Wave Effects on the Coast

Many wave processes are known to affect coastal response over a wide range of temporal and space scales. Longshore and cross-shore transport along beaches, wave-induced erosion along coastal margins (including on the back sides of reconstructed barrier islands), and the role of these processes on the overall sediment balance in coastal Louisiana are poorly understood.

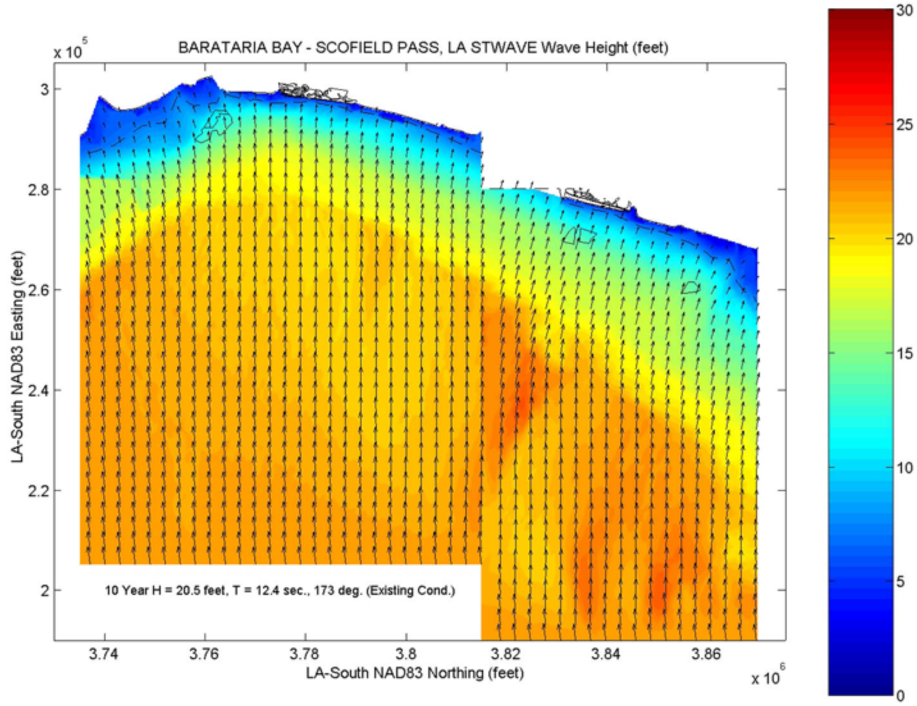
In addition to the direct effects of wave action on movements of sediments and erosion of coastal landforms, waves also play a role in temporary super-elevation of local water levels. Historical data and theoretical arguments have demonstrated that wave set-up is a significant component of storm surge during hurricanes and tropical storms. Wave-driven processes significantly affect both overwash and breaching potential in storms. The direction, duration, and intensity of wave attack superimposed on elevated water levels determine the response of the barrier islands and mainland coastal areas to storm events. During intervals of relatively small waves, wave set-up can play a significant role in raising water levels at the coast. For example, a typical value for set-up is around 20% of the incident (significant) wave height. In areas with large fetches, 2 to 3 foot (0.6 to 0.9 m) waves can create a set-up of 0.5 feet (0.15 m) or so. In coastal Louisiana, set-up contributes significantly to enhanced wave erosion rates.

Larger expanses of open water between barrier islands and the mainland directly lead to three negative factors affecting coastal erosion: increased water levels due to wind stress over larger areas, larger wave heights due to larger fetches, and increased water levels due to wave set-ups associated with higher waves. Reliable wind and wave information will be required to address potential problems that might be created by these processes.

6.3.6 Wave Model Selection and Validation

Inaccurate information is often more misleading than no information, particularly when it comes to environmental issues. Consequently, wave models used in coastal Louisiana should be calibrated and validated in the local area. Extensive shallow, muddy bottoms in this region (e.g. Sheremet and Stone 2003), extensive areas for wave re-generation, and the effects of shoreline irregularities and marsh vegetation on wave propagation all contribute to making southern Louisiana different from sites for which wave models have already been developed, calibrated, and validated. It will be important for wave models in this area to encompass all physical mechanisms affecting wave generation, propagation, and decay (viz. wind inputs, nonlinear wave-wave interaction effects, wave breaking, bottom friction, wave damping by fluidized bottom mud, refraction and shoaling, and wave diffraction). Models such as REFDIF, RCPWAVE, and Boussinesq codes focus only on conservative propagation of waves and cannot treat important processes that contribute significantly to wave conditions in the Louisiana region.

Two computer codes appear to offer the best potential for adapting to this area: STWAVE (Figure D.6- 8) and SWAN. Both codes contain approximations for necessary processes and are available in source-code format, which will simplify their adaptation to this region.



Note that simulated 20.5 feet high waves at deep water (offshore) reach the shoreline with a maximum height of 3 ft. This reduction in wave height is caused by bottom friction over the wide Louisiana shelf.

Figure D.6- 8. STWAVE simulation for the Barataria-Plaquemines shoreline, SE Louisiana showing wave decay across the continental shelf.

An important part of the effort to obtain reliable wave information for this region must be the collection of wave data for calibration and validation purposes. Without such data, no confirmation of wave models is possible.

6.3.7 Statistical Considerations in Barrier Island Restoration

In essentially all environmental decision-making today, it is imperative to consider not only mean conditions but to use risk-based principles to evaluate design and planning alternatives. All too often, failure to consider natural variability has led to incorrect or inappropriate decisions. Therefore, it would be helpful to evaluate the expected variability of natural forcing functions and to estimate the expected impact of any man-made changes over a range of conditions, not just for mean conditions or fixed scenarios.

Of particular relevance to barrier island restoration is the impact of design decisions on the survivability of the islands and on the economics of island restoration. For example, if a project is built to withstand a 10-year wave, and a 50-year wave occurs, the project may be rendered ineffective. The likelihood of an m-year event occurring in an n-year interval is given by the relationship

$$P_n(\chi < \chi_m) = [F(\chi_m)]^n = [1- 1/T(\chi_m)]^n \quad \text{(Eq. 7)}$$

where P_χ (.) is the probability that χ will not exceed cm (the expected m-year value of χ) over an interval of n years; and $F(\chi_m)$ is the cumulative distribution function of an annual set of values evaluated for the return period of m years [$T(\chi_m)$]. This relationship shows that there is about a 50% chance of exceeding a 30-year event over a 20-year interval. Similarly, the chance of exceeding a 50-year event over 20 years is about 33%, and the chance of exceeding a 100-year event over the same timeframe is 18%.

6.3.8 Calibration and Verification of Coastal Models

Calibration and verification are two important steps in running numerical coastal models. Model calibration adjusts input parameters in an attempt to match field conditions within an acceptable degree of confidence. The procedure requires field conditions at the study site to be accurately characterized. Lack of proper site characterization may result in a model that is calibrated to a set of conditions that is not representative of actual field conditions. Calibration requires a level of expertise and understanding of the problem to be solved, as well an understanding of the model being used. For example, shoreline change models are basically sand transport models that use shoreline as a proxy for volume change caused by longshore drift. Where shoreline changes are caused by cross-shore processes, the historic shoreline change should not be used to calibrate or verify the model. In this scenario, sand deposition at spits, against jetties, or at ebb-tidal shoals would be a better calibration tool.

There are different types of calibration to consider, and these rely strongly on the types of questions that are to be answered by the model. For example, one can calibrate a model to reproduce long-term trends, storm events, extreme storm events (e.g. hurricanes), and so on.

Model verification is a procedure in which the calibrated model attempts to reproduce changes that are measured over a different time-interval than the calibration interval. Verification is performed to detect the uncertainty range associated with model application versus measured results. The experienced modeler should also be aware of variations that are expected in the physical system, and consider introductions of new situations or interventions to the system that might invalidate previous verifications.

6.4 Coastal Sediment Applications and Costs

This section discusses the theory, practice, and cost of beach nourishment as applied to barrier island restoration in Louisiana. To be successful, such projects must consider local factors such as sediment composition, natural slopes, inlets, tides, waves, and other unique features of the ecosystem.

Beach nourishment is the process of placing large amounts of beach-compatible sand in the nearshore to compensate for a net deficit of sand in the beach system. Beach nourishment has been the primary shore protection and beach restoration measure used in the United States, Europe, and Australia over the last three decades. As an example, The Netherlands Ministry of development in 1990 declared: "Until now the best response the Netherlands could offer to coastal erosion and the rising sea-level has been sand nourishment. In this way coastal recession can be brought to a standstill. Although nourishments must be repaired on a regular basis, this coastal defense method is attractive from a financial-economic standpoint and is ecologically sound."

In Louisiana, beach nourishment has been used since the early 1980s. LDNR in 1993 said "Experience has demonstrated that the most cost-efficient method of restoration is to use sediment and vegetation to elevate front dunes and to build back barrier marshes."

Nourishment types and approaches are deployed differently around the world and can be distinguished by location and methods of fill placement, design strategies, and techniques (NRC 1995; Hanson et al. 2002; Dean 2002). Types of nourishment include the following (Figure D.6-9):

A. dune nourishment: placing most of sediments in a dune behind the active beach

B. nourishment of subaerial beach: using sediments to build a wider and higher berm above the mean water level, with some sand entering the water at a preliminary steep slope

C. profile nourishment: distributing the sediments across the entire beach profile, including the submerged profile

D. bar or shoreface nourishment: placing the sand offshore to form an artificial "feeder" bar

For economic reasons, Type B, (nourishment of the subaerial beach) is the most common nourishment practice in the United States and world. Placement of fill on the subaerial beach often results in an initially wider beach berm than the targeted design width, due to steeper construction slopes that eventually equilibrate to milder natural slopes through post-construction wave action. Typical components of Type B nourishment are illustrated in Figure D.6- 10.

Type A (dune nourishment) has been previously applied and is also considered for future restoration of Louisiana's barrier islands (e.g. LDNR 1993; Van Beck and Meyer-Arendt 1982; T. Baker and Smith 1998). Although many projects feature the construction of dunes, subsequent equilibration of the diked profile is anticipated by the designers, and therefore long-term performance would be a combination of Types A and B. Sand dunes can be an important protective feature, especially for barrier islands. Constructed projects could therefore reinforce existing dunes by increasing height/width, or by constructing new dunes. Dune height is a factor that affects the islands' susceptibility to storm overtopping and overwash.

Evolution of natural dune crests is variable, and low spots in the dunes may be susceptible to island breaching during major storms. Dunes and berms built with consistent elevations during nourishment projects can reduce the potential for island breaching (USACE 2002).

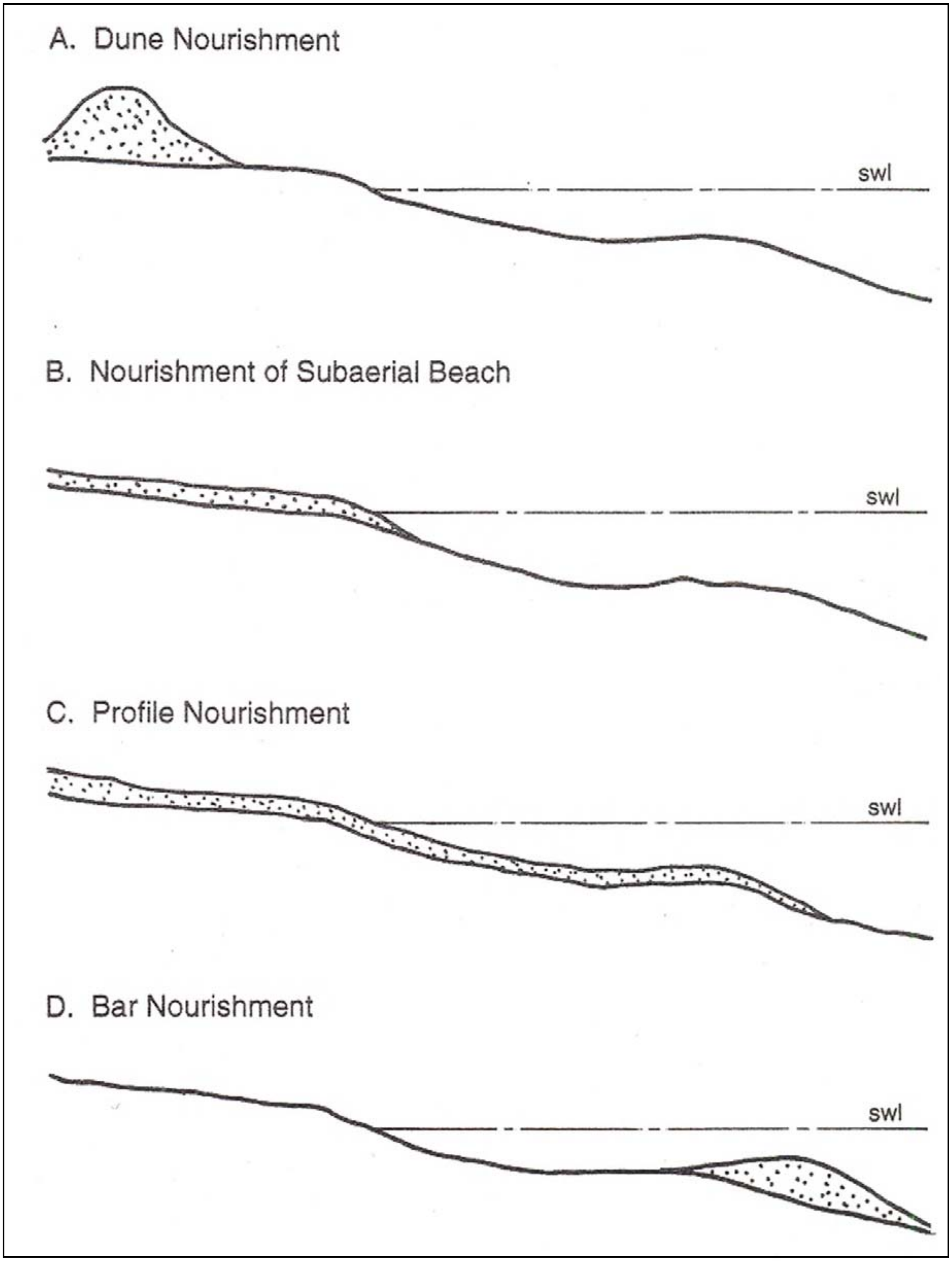


Figure D.6- 9. Types of nourishment as a function of fill location.

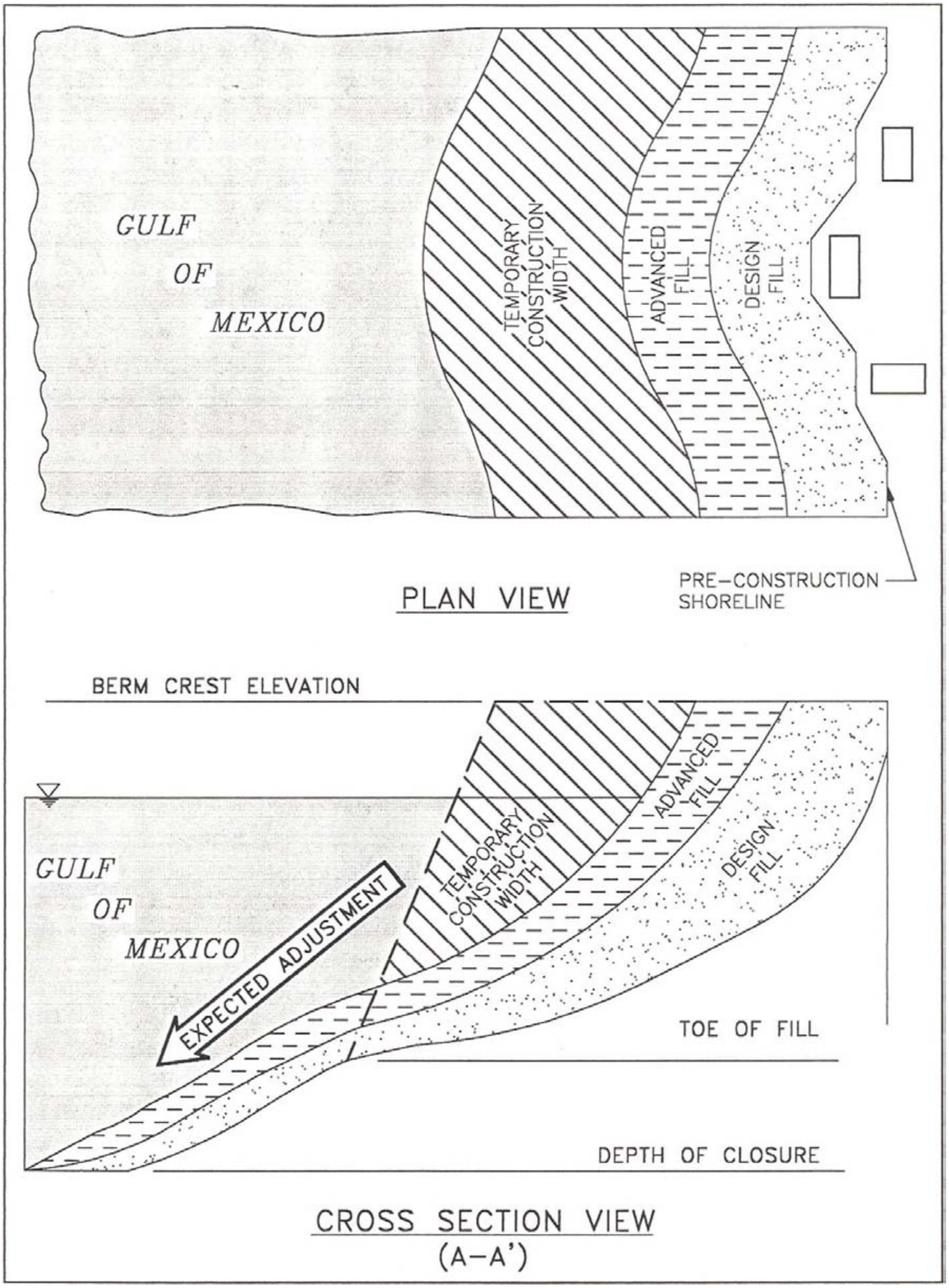


Figure D.6- 10. Illustration of the common components of a subaerial beach nourishment (Type B) and the adjustment expected after initial construction.

Beach nourishment is not a new engineering technique; the first such project in the United States dates back almost a century (Coney Island, NY, 1923). Successful beach nourishment is not created by a single construction project, but rather is program of periodic constructions that maintain a stable beach system in the long-term. In other words, beach nourishment is a journey, not a destination (Campbell 2002). Most successful beach nourishment programs employ an adaptive management design. This design incorporates monitoring and design adjustments in the form of periodic renourishments that improve project performance.

Beach nourishment projects typically involve constructing one or several of the following features: berms, dunes, and stabilizing or terminal structures. The amount of additional beach width should be determined by an iterative process that evaluates costs and benefits as a function of width.

Technical and economic considerations need to be taken into account when implementing nourishment programs along a discrete segment of coastline. These considerations, according to NRC (1995) and the LCA Science Workshop (2003), include:

- establishing baselines and objectives (goals and expectations of the project)
- determining costs and benefits
- testing available theory and techniques that form the basis for design and prediction of project performance
- searching for borrow sources and evaluating the suitability of borrow location and materials
- constructing initial nourishment projects
- monitoring initial projects
- validating preliminary assumptions
- identifying design strengths and deficiencies
- evaluating design and predicting procedures
- developing design refinements
- developing and maintaining a public awareness program
- basing decision making on whether to renourish on monitoring data and design expectations
- improving initial design processes in the design of the subsequent renourishment

Because performance is determined mainly by the project’s interaction with the environment, the effectiveness of beach nourishment can be increased by understanding the coastal system in which the project is being built. Common parameters to consider include: spatial location of project, geology/geomorphology/sedimentology; small and large scale coastal process (longshore drift, littoral cells, wave climate and frequency of storms, beach morphodynamics and others) and their time-dependency; and presence of infrastructure. A project located on an open coast will perform quite differently from a project adjacent to an inlet or bay system. Project performance differs if the nourishment is located adjacent to stabilized inlets or non-stabilized channels. These factors should be considered in order to improve performance of the nourishment program.

6.4.1 Applications of Model Concepts to the Design of Beach Nourishment

There is no magic formula that can be applied uniformly in the design and evaluation of beach nourishment programs. Rather, each design must be adapted to local conditions. Two dominant processes are relevant to the design and performance of most beach nourishment projects: cross-shore profile equilibration, and lateral spreading of fill material to adjacent beaches (Figure D.6- 11) (NRC 1995; Dean 2002). Other processes that account for loss of sediment from the active beach system include: response to sea level rise and subsidence (LCA science workshop 2003; Penland and Ramsey 1990), loss of sediments to expanding tidal shoals (Fitzgerald et al. 2003), and overwash processes (CPE 2003). In Louisiana, the processes that should be measured and incorporated into nourishment design include:

- overwash
- profile response to relative sea-level rise
- sediment loss to ebb-tidal shoals.
- spreading and longshore losses (less important or insignificant when entire islands are restored)
- cross-shore profile equilibration of nourished profiles (Initial adjustments can be very important on diked constructed profiles.)

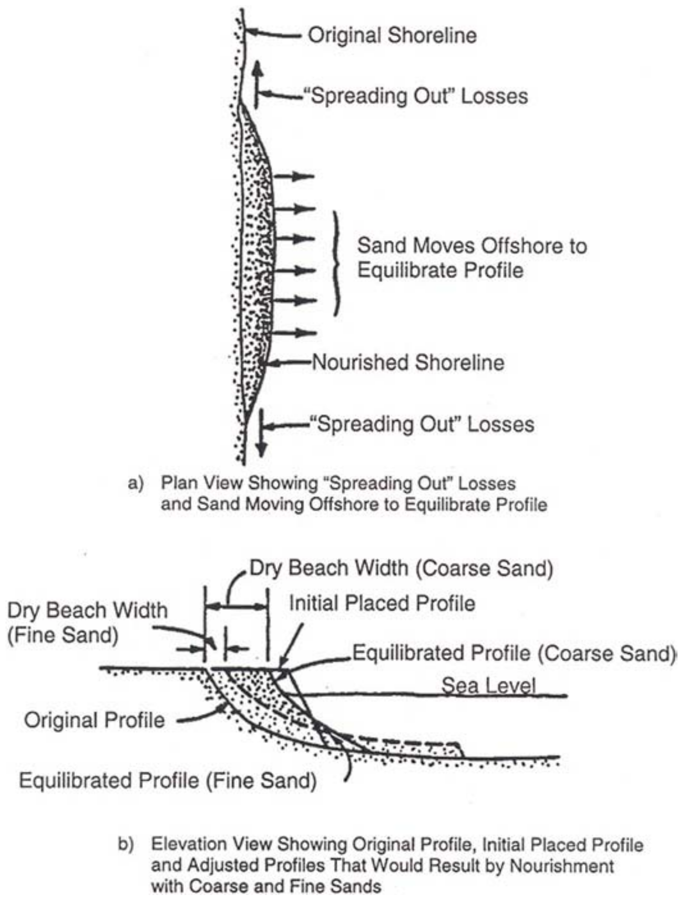


Figure D.6- 11. Schematic diagram illustrating the two dominant processes (lateral spreading and cross-shore equilibration) in the design and performance of most beach nourishment projects (after NRC 1995).

The evaluation of compatibility between native and borrow sands dates back to the late 1950s when Krumbein (1957) and subsequent researchers (e.g. James 1975; SPM 1984) described a simplified method to empirically translate these processes into two different parameters: the overfill factor (RA) and the renourishment factor (RJ). The overfill parameter (RA) addresses differences in grain size and sorting between borrow and native beach sediments. The overfill parameter also predicts the volume of borrow material necessary to produce a stable unit of fill material (the same grain size as the native beach sand). The renourishment parameter (RJ) relates to the finer borrow material's greater susceptibility to suspension and transport. This parameter also estimates renourishment needs.

Recent work conducted by Dean (1991, 2000, 2002) questions the use of these grain size factors (RA and RJ) to estimate beach fill volumetric requirements and performance. Present design approaches favor the use of equilibrium profile considerations, longshore spreading of beach fills, and background erosion rates to replace the overfill and nourishment factor approaches (NRC 1995; Dean 2002; USACE 2002).

The equilibrium profile method is based on the premise that a nourishment project represents a disturbance of the system's equilibrium. Analysis of the initial performance of a fill project can thus be based on the process of returning the system to equilibrium. Particularly for beach nourishment design, it is important to estimate the dry beach width that results after profile equilibration.

According to Dean (1991, 2002), nourishment projects that use finer sands than what is found on native beaches will produce milder slopes and generate non-intersecting profiles. Coarser sands will exhibit steeper slopes and generate intersecting profiles, and similar sands will replicate the natural beach profile (non-intersecting profile) (Figure D.6- 12). Intersecting profiles translate to greater subaerial beach volumes per cubic yard of sand placed on the beach, while nonintersecting and submerged profiles are characterized by a distribution of the fill across the beach profile and therefore less subaerial beach area per cubic yard of fill placed (Figure D.6- 12). The current Louisiana sand profile is representative of intercepting profiles, with sands intercepting the flatter fine sediment (silt, clay) profile. The same profile shapes and performance should be expected during large restoration projects, where sandy sediments will anchor in offshore fine sediments (silt and clay).

Further details and case studies of the equilibrium profile method for the design of beach nourishment projects are available in Dean (2002) and USACE (2002).

Cross-shore responses of nourished profiles to storms can also be predicted by profile numerical models, such as those described by Larson and Kraus (1989-SBEACH). Application of these models must, however, consider capabilities and limitations, and they must be calibrated and verified. Because the Louisiana nearshore profile contains both sand and fine sediment (silt and clay), the SBEACH model may require modification before it can be used for prediction and design.

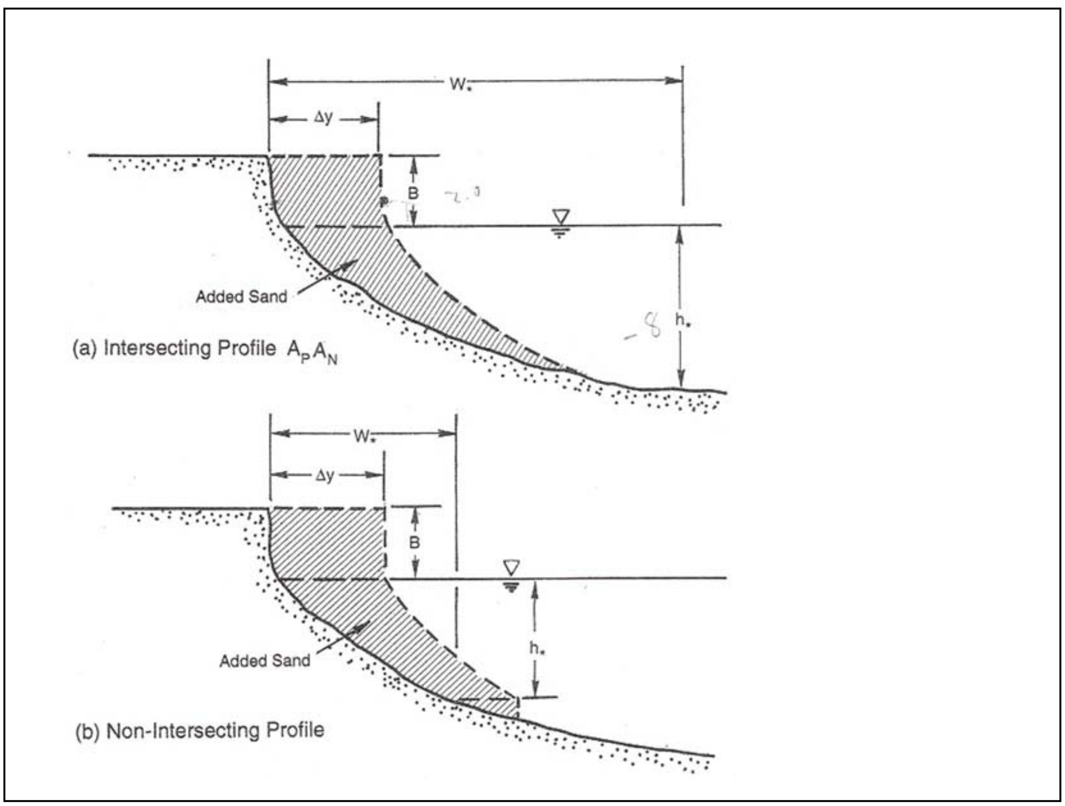


Figure D.6- 12. Generic profile types as a function of grain size (after Dean 1991).

Lateral spreading of placed sand results in the loss of nourishment sand to adjacent shorelines, as illustrated in Figure D.6- 13. Lateral spreading of beach fill is a function mainly of fill length and width, grain size, boundary conditions, wave climate, and background erosion rates. There are different methods to estimate the lateral spreading of beach fill; they range from simplified analytical models (e.g. Dean and Yoo 1992) to detailed numerical models (e.g. Hanson and Kraus 1989).

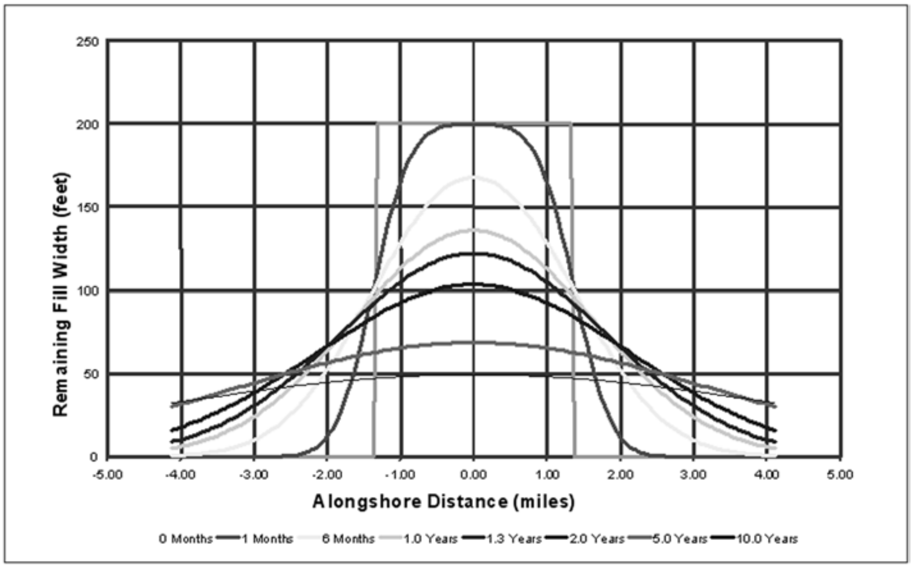


Figure D.6- 13. Hypothetical example of longshore spreading of beach fills on an open coast.

The GENESIS model of Hanson and Kraus (1989) should be applied with caution in the sandy/fine sediment coast of Louisiana (see above—Coastal Models). It is unlikely that application of the GENESIS Model in its current form will give meaningful results in Louisiana, where most shoreline retreat is caused by factors other than longshore transport gradients.

For Louisiana's shoreline, where entire islands will be restored, other processes such as overwashes during storms, breaching, and cross-shore equilibration generally will play a more important role than spreading. However, if a sand headland is extended over a limited segment of beach to protect infrastructure, lateral spreading of material could become a dominant process.

6.4.2 Project Cost Analysis

The cost of dredging sediments from the Gulf of Mexico for the purpose of barrier island restoration is affected by the following factors:

- type of sediment (sand, silts, compacted clays, combinations of sands, silt, and clays, etc.)
- distance from the borrow area to the barrier island
- length and width of the barrier island to be restored
- depth of water and depth of dredging in the borrow area
- depth of water adjacent to the barrier island

- o thickness of the dredge cut

The type of sediment determines the horsepower requirements of the dredge, which in turn affects the cost of dredging. For example, if a hydraulic cutterhead dredge is used to dredge sand and silt from two identical borrow areas, the silt dredging will be cheaper because the horsepower requirements for dredging silt are less than for sand. If clays are encountered in the borrow area, the horsepower needed to excavate clays is much greater than sands (due to compaction), and the transport of cohesive sediments is also more energy intensive.

The occurrence of clay layers in the borrow area may also dictate the types of equipment that may best dredge the borrow area. There are three types of dredges: mechanical, pipeline (e.g. cutterhead) and hopper. The latter two are most frequently used in beach nourishment projects. Hopper dredges and the ocean going dustpan pipeline dredges use hydraulic jets to loosen and fluidize the sediment. While hydraulic jets work well in silts and sands, they are not efficient in working with consolidated clays. Cutterhead pipeline dredges use rotating cutter heads to cut and fluidize the sediment. Cutterhead pipeline dredges are more efficient than hopper dredges in cutting through clay layers.

The distance from the borrow area to the extreme limits of barrier island restoration also affects project cost and equipment selection. When dredging and pumping distances up to six miles, a pipeline dredge is the most efficient method. These dredges typically have 10,000 to 15,000 horsepower, which can pump noncohesive sediments efficiently over long distances. When the distance from the borrow area to the barrier island exceeds six miles and water depths near the project site allow navigation, then hopper dredges can be more efficient in transporting the sediment. The draft requirements of an ocean going hopper dredge vary between 15 to 30 feet depending on the size of the dredge. In Louisiana, theses depths only occur along three to six miles of the coastline. Therefore, hydraulic hopper dredges may not be suitable in some cases due to their limited ability to access fill areas. The use of smaller barges to transport the material through shallow water or dredging access channels can overcome this limitation. However, using barges will increase the unit cost of material. In addition to depths of disposal sites, the remote sand source (offshore borrow areas) depth should be no less than 15 feet and ideally 30 feet to enable access for a relatively large and fully loaded vessel. Hopper dredges are not equipped with significant horsepower for pumping out, so booster pumps may be required.

A combination of dredge technologies (e.g. pipeline and hopper) can sometimes be used to reduce costs. Two projects on Florida's east coast were constructed using this combination of dredges. In these projects, the hopper dredges excavated sand from distant borrow areas and transported it to a nearshore rehandling area. The hopper dredges were then bottom dumped. Pipeline (cutterhead) dredges re-dredged this material and pumped it to the beach at high production rates. This method was cost effective for this particular application. Similar combinations of dredges may also provide advantages in Louisiana. It may also be possible to use existing navigation channels to transport and re-handle material (e.g. Port Fourchon could be used as an access channel for Ship Shoal sands).

The length and width of the barrier island restoration also affects the total volumetric requirements and length of pipe needed for a given project. This in turn will affect the final project cost. The length of pipe necessary to reach all parts of the island must be considered in dredge selection and when forecasting production rates. The use of multiple pipe landings reduces pipe lengths but also requires multiple pump-out locations.

Thickness of cut in borrow areas also affects equipment selection and productivity. For cutterhead dredges to be productive, the cut must be at least eight to nine feet thick. For cuts less than eight or nine feet, cutterhead dredges operate at less than optimum efficiency. For shallow cuts, hopper dredges and the ocean going dustpan are more efficient because they can excavate sediments in layers.

6.4.3 Estimate of Dredging Costs

In order to develop a restoration program for the Louisiana barrier islands, the dredging costs, transport, and placement of sediments can be estimated. The cost of dredging is usually bid in three parts: (1) the mobilization-demobilization, (2) the unit cost of dredging, transporting, and placing a cubic yard of sediment, and (3) the cost of building and removing containment dikes when required. These costs are described in detail in the next sections.

The mobilization expense is the cost for the contractor to deliver all equipment and personnel to a job site to initiate construction. This includes not only the dredge, pipeline, booster pumps, personnel, bulldozers and pipe loaders, but also administrative items such as field office requirements, the cost of insurance and bid and performance bonds, as well as overhead and profit. Currently, there are only five contractors on the East and Gulf coasts of the United States with the ocean certified dredges that can complete beach nourishment on the Louisiana coast.

The demobilization cost is the cost of removing all equipment and personnel from the project site. This cost may also include site restoration costs and final surveying costs. There is always some travel distance associated with demobilization, because the equipment and personnel must be removed from the existing project site. The actual estimation of mobilization costs can be performed by using the following methods:

(A) USACE Spreadsheets. The USACE Headquarters developed detailed spreadsheets for estimating dredge mobilization costs. There is one spreadsheet for each type of dredging (pipeline, hopper, and mechanical). The spreadsheets were developed in the early 1990s with input from the dredge industry. The spreadsheets require the inclusion of many variables, which may be well known to a dredge contractor, but not to an estimator. For example, one variable involves calculating the depreciation of a 15-year old hopper dredge. The spreadsheet software and manuals are not released to any sources outside the U.S government.

(B) Comparable Cost (Experimental) Approach. A comparable cost estimate is based on previous dredge projects. For projects utilizing less than three or four miles of pipeline, one dredge, and no booster pumps, $1 million is a typical mobilization/demobilization cost. If more than four miles of pipe are involved in the project, or if a booster pump is required, than an additional $0.5 to $1.5 million may be expected as part of mobilization and demobilization costs. The recent mobilization-demobilization costs for barrier island restoration projects in Louisiana are shown in Table D.6- 1.

Table D.6-1 Sample of previous mobilization and demobilization cost for some Louisiana barrier island restoration projects.

Project Name	Mobilization/ Demobilization Costs ($)	Notes
East Timbalier Sediment Restoration Projects (2002)	$1, 050, 000	
Holly Beach Sand Management Projects	$1,900,000	Approximately8 miles of pipe and a booster pump were mobilized.

The cost of dredging, transporting, and placing sediment involves the operational cost of the dredge, personnel, and land based equipment. The cost of field office support, surveying, compliance with environmental protection, and corporate overhead and profit are usually included in the unit cost of dredging. There are several approaches to estimating the unit cost of dredging.

Previous experience can be used as a guide for estimating unit (price per cubic yard) dredge costs. Hopper dredge costs may be estimated using a base cost for dredging and pumping out the sediment, plus an incremental cost, which is related to the distance from the borrow area to the pump out location. Two commonly used estimates are:

Cost/cy = $4.00 + $0.50/mile, (Eq. 8)

or

Cost/cy = $7.00 for distances up to 8 miles +
$0.25/mile for each mile over eight miles, (Eq. 9)

where the distance is a one way travel measurement. During the bidding of the Holly Beach sand management project, LDNR requested bids for the dredging of sand from the Sabine Banks, which was 16 nautical miles from the beach at its closest point. The lowest bid had a unit cost of $11.00/cy. Equation (8) would suggest a unit price of $12.00/cy, while Eq. 9 would give a unit cost of $9.00/cy. These relationships should be refined based on more Louisiana hopper dredging projects.

In Louisiana, the shallow continental shelf may restrict hopper dredges from coming closer than two to three miles (e.g. Chenier Plain) to four miles offshore (e.g. Isles Dernieres chain) of the fill areas due to the dredges' fully loaded draft requirements (15 to 30 feet but optimally 30 feet). Longer distances will raise the base cost due to longer pipe lengths and production reductions.

The availability of a specific type of dredge (pipeline or hopper) at the time of bidding may also affect the actual cost. If the needed dredges are unavailable, mobilization and/or unit dredge costs may increase between 25 and 100%. This can be avoided by bidding projects as soon as possible, and by being flexible with the contract times (notice to proceed, dredge start, and substantial completion).

Unless specified, all costs represent the cost of fill measured in place, not by the cut of the borrow area. If it is specified in the contract that the dredge contractor will be paid by the volume of fill placed on the beach, the contractor will have to develop strategies to meet the design template in order to be paid. This practice may increase the cost per cubic yard of material, but the final project costs could actually be reduced by avoiding uncertainties (e.g. dependency on variable cut to fill ratios). Because of the limitations of as-built templates in marshes, pay-by-the-hole may be appropriate for marsh restoration projects.

6.5 Coastal Structure Applications

6.5.1 Summary

This section discusses methods for restoring barrier islands using the following six hard structures: seawalls, revetments, terminal groins, groins, breakwaters, and jetties. The pros and cons of each method are presented, along with their approximate costs.

The coastal structures discussed below can be successfully engineered to fulfill a primary goal (protect property, stabilize navigation channels, and so on). However, these structures can also have secondary, and less desirable, impacts on the coastal system.

6.5.2 Seawalls

Seawalls are rigid coastal structures that are primarily constructed of steel sheet pile or concrete panels (e.g. Figure D.6- 14). The purpose of seawalls is to protect the upland infrastructure (homes, roads, or critical utilities), not reduce alongshore sediment transport or widen the beach.

Figure D.6- 14. Seawall built to protect a beach-front hotel in Panama City, Florida on the gulf coast (Panhandle). Picture taken in 1998 before the construction of the Panama City Beach Erosion Control and Storm Damage Reduction project.

Seawalls limit the movement of sediment from behind the seawall to the active littoral system seaward of the wall. The lack of cross-shore transport from the dune to the beach may result in scour features at the base of the structure. Scour features may occur due to wave reflection at the seawall and/or longshore gradients in the littoral drift. Wave reflection will result in cross-shore movement of sand in the active profile but no volumetric loss. Longshore gradients in littoral drift will cause erosion of the submerged profile until sediment transport into the seawall/protected area equals the amount of sediment to the downdrift beach. An extreme example of this process can be seen along the west end of the Galveston seawall.

If there is erosion of the beach and dune system, the seawall and its associated return walls can act as a groin and cause sand accumulation updrift of the structure and corresponding erosion downdrift. Thus, while seawalls do not cause erosion, they can transfer erosion from updrift shorelines to downdrift shorelines.

Use of seawalls in coastal Louisiana may be limited due to the migrating nature of the barrier islands, and is only suggested if all the conditions below can be met:

- Protection of infrastructure is required.
- Barrier island migration is low, or will be controlled through beach and dune nourishment.
- Adequate sand is maintained on the beach to avoid alongshore interactions.
- The seawall is shown to be the most cost effective method for protecting infrastructure.

The cost of a sheet pile seawall can be generally estimated at $1,000 per linear foot. This includes mobilization costs, materials, and installation. Factors that may increase the cost include but are not limited to: site access difficulties, poor geotechnical conditions, and remote locations.

A seawall can also be used for the temporary closure of a tidal pass or breach. Since coastal Louisiana contains numerous passes and island breaches, it may be desirable to close certain tidal entrances to improve the long-term survival of barrier islands. Construction of a cantilevered seawall across a breach may be necessary to eliminate tidal flows and enhance hydraulic filling of the pass. Sand can then be placed to re-establish the barrier island. Once sand is in place, the sheet pile seawall can either be removed or left as is.

6.5.3 Revetments

Revetments are similar to seawalls in their purpose (protecting upland property) and in their interaction with coastal processes. The structures are constructed as rubble mounds, with the stone size determined by analysis of the wave climate. In Louisiana, the cost of rubble mounds is relatively low due to the availability of stone.

Rocks placed on sediment can settle significantly. Some form of foundation protection (e.g. rock filled geotextile) is needed to limit this settlement. In some cases, the ground may be too unstable to support rock structures, even with foundation protection.

Revetments limit the movement of sediment from behind the revetment to the active littoral system seaward of the wall. Due to the energy dissipating nature of rubble mound construction, the probability of scour is reduced for a revetment versus a seawall. Revetments have the same longshore considerations and effects as seawalls (see above).

Revetments have been built previously to protect Louisiana's barrier islands (e.g. Timbalier Island in the early 1980s). In one case, storms overtopped the revetment and the island. This caused the barrier island to migrate away from the revetment. In March 2000, the construction of a revetment was finished in East Timbalier Island (Picciola and Associates 2000). However, no significant effects have been noted to date (e.g. Penland et al. 2003), and the island continues to erode and retreat along with the neighboring islands (Figure D.6- 15).

Figure D.6- 15. Recently built rubble mound revetment at East Timbalier Island (looking east).

If there is erosion of the beach and dune system, the revetment can act as a groin and cause sand accumulation updrift of the structure and corresponding erosion downdrift of the structure. Thus, while revetments do not cause erosion, they can transfer erosion from updrift shorelines to downdrift shorelines.

- The use of revetments in coastal Louisiana if all of the conditions below are met:
- Protection of infrastructure is required and not feasible by other means.
- The revetment is shown to be the most cost effective method for protecting infrastructure.
- Barrier island migration is low, or will be controlled through beach and dune nourishment.
- Adequate sand is maintained on the beach to avoid alongshore interactions.
- Existing soils can support rock placement.

The cost of engineered revetments is estimated at $500 per linear foot based on a unit cost of stone at $40 per ton. Factors that may increase the cost include but are not limited to: site access difficulties, poor geotechnical conditions, and remote locations.

6.5.4 Terminal Groins

Terminal groins are shore perpendicular structures constructed at the ends of barrier islands or littoral cells. They can also be located adjacent to non-stabilized inlets in order to avoid or minimize losses to these water bodies (e.g. Figure D.6- 16). These structures are usually shorter than jetties, although they may be built in much the same way.

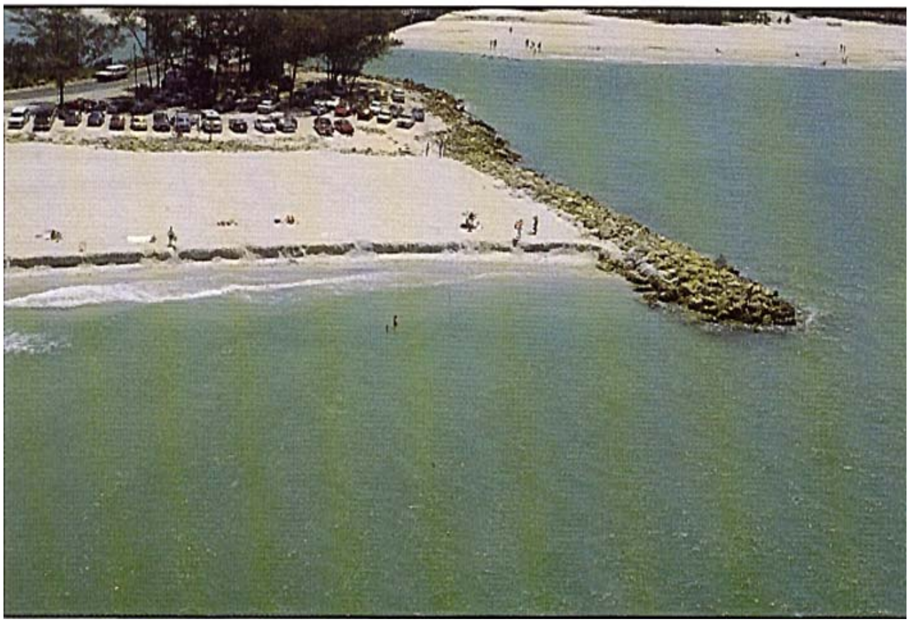


Figure D.6- 16. Terminal groin on Captiva Island, Florida southwest Gulf Coast. The beach fill is located to the left of the photograph and Blind Pass is shown to the right.

Terminal groins are usually constructed as rubble mounds, although sheet pile walls have been used in some locations. The rubble mounds reduce wave energy through wave dissipation. If the groin and stone dimensions are sized correctly, sediment transport through the structure is significantly reduced. Some terminal groins have been designed with impermeable cores (sheet piles or similar) to eliminate sediment transport through the structure. The cost-effectiveness of eliminating sediment transport versus reducing transport should be evaluated prior to designing impermeable cores.

Terminal groins have been proposed in a number of cases to enhance the restoration of Louisiana barrier islands (e.g. van Beek and Meyer-Arendt 1982; T. Baker & Smith 1998). If terminal groins are constructed in coastal Louisiana, they should have a crest width of four armor stones. This will enable future maintenance of the structure (e.g. raise it in response to relative sea-level rise), with an additional layer three stones wide, which is the USACE recommendation (USACE, 2002).

Coastal Louisiana has a wide variety of sand and silty sediments. Terminal groins will exert stresses to the foundation sediments of between 1,000 to 2,000 psf causing settlement. A foundation can be designed to reduce settlement, and pre-construction geotechnical investigations can help designers to identify foundation needs.

Several of Louisiana's barrier islands are convex in shape on the Gulf of Mexico side. In these cases, in order to effectively limit sediment transport off the island, more than one groin may be required. Sediment transport evaluations can be utilized to determine the appropriate number and length of these groins.

The decision to build a terminal groin and the length of the groin can be based on an economic decision. Since the terminal groin will reduce alongshore losses from the beach, the reduction in future sediment losses (island restoration costs) can be compared to the construction cost increase due to the groin.

Several of Louisiana's barrier islands are migrating due to other processes (e.g. overwashes, profile response to relative sea level rise) besides longshore losses to tidal passes. As a result, the use of terminal groins on these islands may not be appropriate, since migrating islands could move away from the terminal groins and allow flanking of the landward end of the groin. Flanking would allow alongshore losses to the adjacent passes, thus defeating the original purpose of the groin.

- The use of terminal groins in the restoration of the Louisiana barrier islands should only be considered if all of the conditions below are met:
- Barrier island migration is low, or will be controlled through beach and dune nourishment.
- The alongshore sediment transport and losses to tidal passes are sufficient to warrant construction of the groin.
- Soil properties are adequate for rock placement, or the foundation can be stabilized.
- Downdrift beaches or islands will not be adversely impacted or will be mitigated for.
- The addition of the terminal groin to the overall restoration program is cost effective.

The cost of a terminal groin without an impermeable core will be directly proportional to the water depth it is built in and the elevation of the structure crest. As a first approximation, terminal groins are built in a trapezoidal shape with the volume of stone per linear foot approximately 3.5 times the square of the total height of the structure. Based on a unit cost of $40 per ton for stone, a linear foot cost of $1,000-$1,200 can be expected. This estimate assumes no voids to provide for construction contingencies. Factors that may increase the cost include but are not limited to: site access difficulties, poor geotechnical conditions, and remote locations.

6.5.5 Groins

Groins are shore perpendicular structures that are designed to trap alongshore sediment transport (Figure D.6- 17). Groins have been constructed from many different materials including steel sheet pile, concrete sheet piles, wood panels with wood piles, and rubble mounds (including concrete roadway and sidewalk debris). Groins are typically designed to extend from the dry beach across part of the surf zone. The amount of sediment transport that is trapped is controlled by the length of the groin.

Figure D.6- 17. Typical groin field (extracted from Douglas 2002).

There are few groins in coastal Louisiana, but there have been numerous applications in other states. Because groins limit or halt erosion by slowing the drift in the protected area, downdrift beaches may be adversely affected by not receiving the sediments that would have been eroded from the protected area. A detailed littoral budget is required to determine if a groin field will cause downdrift erosion and how far downdrift of the erosion area the field needs to be extended to avoid downdrift effects (Campbell and Jenkins 2000).

In Louisiana, the alongshore sediment transport is usually a small percentage of the total transport on the barrier islands. As a result, groins may not be effective.

The cost of groins is proportional to the construction materials. Costs ranging from $500 to $1000 per linear foot should be expected.

The use of groins in the restoration of the Louisiana barrier islands is suggested if all of the conditions below are met:

- Barrier island migration is low, or will be controlled through beach and dune nourishment.
- The alongshore sediment transport is sufficient to warrant construction of the groins.
- The groin field is filled with sand.
- It can be demonstrated that downdrift beaches will not be adversely impacted.
- The addition of the groins in the overall restoration program is cost effective.
-

6.5.6 Breakwaters

The main function of breakwaters is to trap sand by reducing wave energy behind the structure, therefore slowing littoral drift and often creating a salient or tombolo behind the structure. There are two main types of breakwaters:

(a) emerged - minimal wave transmission and overtopping depending on crest height, width, material, and wave climate. Provides wave shadow behind the structure.

(b) submerged - permits greater amount of wave transmission, also called reef structures.

Segmented breakwaters (series of offshore breakwaters) are another structural method for controlling alongshore sediment transport and possibly cross-shore transport. Breakwaters are constructed as rubble mounds and placed parallel to and near the shoreline. Breakwaters dissipate and redirect wave energy. They have been constructed in Holly Beach (Figure D.6- 18), Raccoon Island, Port Fourchon headland, and at Grand Isle with various degrees of success. A proposal for installation of submerged breakwaters in Rockefeller Wildlife Refuge is under consideration (Shiner and Mosley 2003).

Figure D.6- 18. Segmented breakwater system of Holly Beach, LA shortly after the beach nourishment (March, 2003 photo taken by Victor Monsour's Photograph, Inc.).

Local shoreline responses to breakwaters range from minimal change, to mild shoreline undulations often referred to as salients, to shore connecting sand ridges called tombolos. When addressing erosion caused by gradients in littoral drift, a long uniform series of breakwaters (e.g. Holly beach) may reduce, but not eliminate, beach erosion.

Due to the trapping capability of long breakwater fields, these structures deprive downdrift beaches of sediment. Since erosional areas usually experience increasing gradients of littoral drift, breakwaters designed to stop erosion should keep the littoral drift constant in that area to avoid downdrift erosion. The breakwater must extend along the erosion area and into the downdrift accretion area where the littoral drift is again equal to the rate that enters the updrift end of the field (Campbell and Jenkins 2001).

Because of end effects, a limited number of breakwaters (say five) will be more efficient than large numbers on long breakwater fields such as Holly Beach. The ends of a long breakwater system will be more effective than the middle because of sand sharing with adjacent non-protected areas (e.g. Holly Beach, CPE 2000).

Breakwaters cost about the same as other rubble mound structures. The system of 85 breakwaters constructed at Holly Beach, Louisiana (Chenier Plain), was installed at a cost of approximately $100,000 for each 175 foot long structure (on average), or approximately $425 per linear foot. The price for other breakwater systems in Louisiana may vary from $500 to $1,500, depending on site accessibility, structure characteristics, and rock price.

The ability to control cross shore transport (island migration) through the use of segmented breakwaters is largely untested and unproven. Pilot demonstration projects are, however, currently being tested and monitored (e.g. Raccoon Island, Stone et al. 1999). It should be noted that breakwaters become less effective as their distance from the shore increases.

Breakwaters should only be considered for the restoration of Louisiana barrier islands if all of the conditions below are met:

- Barrier island migration is low, or will be controlled through beach and dune nourishment.
- The alongshore sediment transport is sufficient to warrant construction of the breakwaters.
- The breakwaters are filled with sand.
- Downdrift beaches will not be adversely impacted (or adverse effects will be mitigated).
- The expected shoreline response and the littoral transport can be accurately predicted.
- There is sediment availability in the system to support the salient/tombolo formation.
- The addition of the breakwaters in the overall restoration program is cost effective.

6.5.7 Jetties

Jetties are shore perpendicular structures constructed at the ends of barrier islands to reduce alongshore sediment transport into an adjacent pass or inlet and maintain a navigation channel within the pass. The length of jetties is long compared to terminal groins because they are intended to stop littoral drift into the pass and reduce wave transmission into the navigation channel. Jetties may have negative downdrift effects, as observed in the downdrift shore of the Empire (Figure D.6- 19) and Belle Pass jetties.

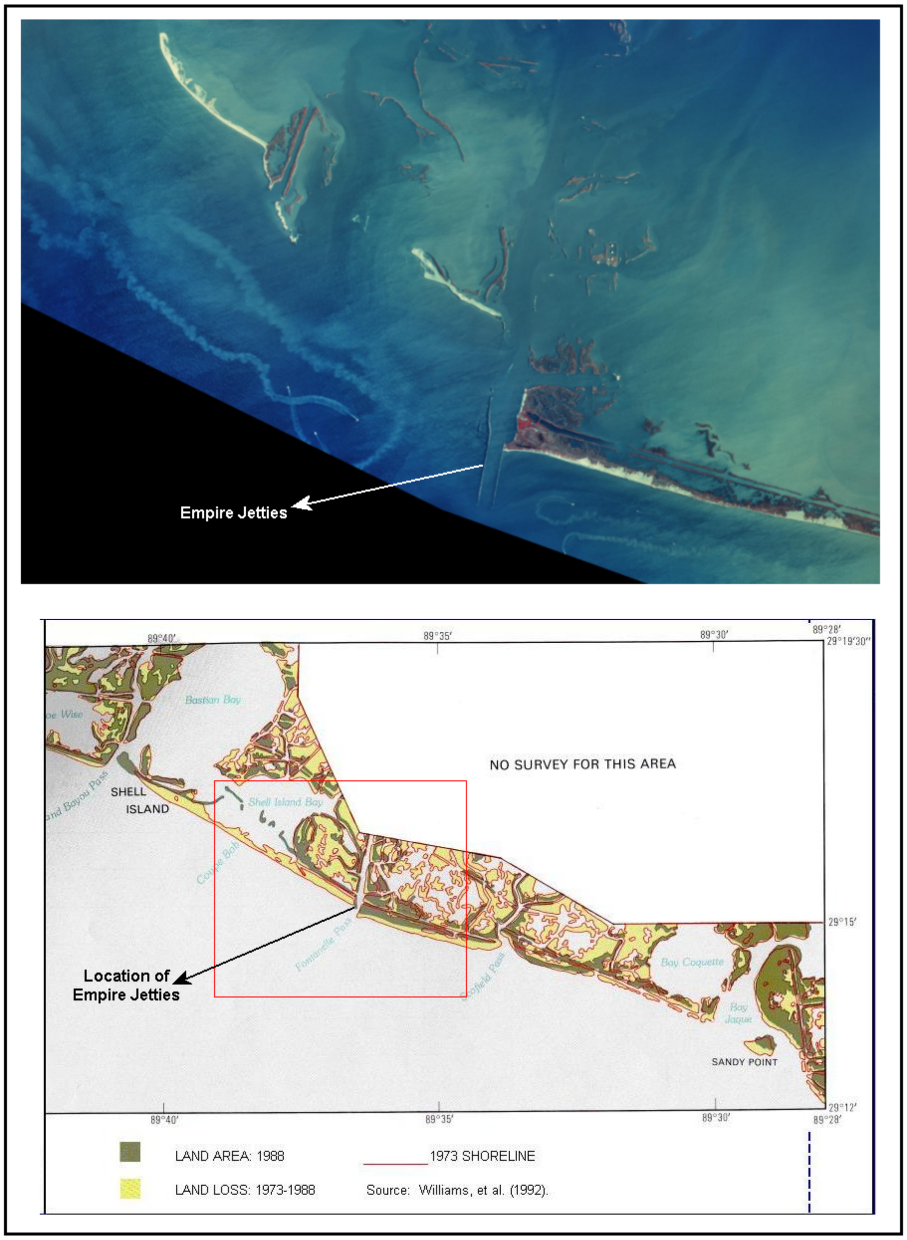


Figure D.6- 19. Empire Jetties located on the SE segment of the Plaquemines shoreline. The picture on top shows remnants of downdrift barrier islands severely eroded, breached, and located away and landward from the jetties. Note: on the land loss map (bottom figure), the pre-existing Shell Island was severely eroded after jetty placement (between 1973 and 1988).

Jetties are usually constructed as rubble mound structures to dissipate wave energy. When the jetty and stone dimensions are sized correctly, sediment transport through the structure is significantly reduced. Some jetties have been sealed to reduce or eliminate sand leakage through the structure.

Because several of the barrier islands are rapidly migrating, the use of jetties may not be appropriate as the barrier islands could migrate away from the jetties and allow flanking of the landward end of the structure. This flanking would allow alongshore losses to the adjacent passes.

If jetties are constructed in coastal Louisiana they should have a crest width of four armor stones to enable future maintenance of the structure (e.g. raise the structure in response to relative sea level rise, with an additional layer three stones wide, which is the USACE recommendation (USACE, 2002). Rock jetties should only be considered on foundations that are designed to limit settlement.

Use of jetties in the restoration of the Louisiana barrier islands should be considered if all of the conditions below are met:

- Barrier island migration is low, or will be controlled through beach and dune nourishment.
- The alongshore sediment transport and loss to the inlet is sufficient to warrant construction of the jetty.
- Existing or future navigation needs require the structural stabilization of the navigation channel.
- The addition of jetties in the overall restoration program and the navigation project are cost effective.
- Downdrift beaches will not be adversely impacted (or adverse effects will be mitigated).

-

Jetty cost is directly proportional to the water depth and the elevation of the structure crest. Jetty cross-sections may be built in a trapezoidal shape. Thus, a first estimate of the volume of stone per linear foot is approximately 3.5 times the square of the total height of the structure. Since the total height of the structure varies with water depth, a non-site specific estimate is difficult. Based on a unit cost of $40 per ton for stone and assuming there are no voids in the structure, a linear foot cost of $2,000-$4,000 can be expected. Factors that may increase the cost include, but are not limited to: site access difficulties, depth of the navigation channel, poor geotechnical conditions, and remote locations.

6.6 Vegetative Plantings

6.6.1 Summary

Three primary elements contribute to the diversity and function of natural coastal plant communities and form the basis for coastal habitat restoration protocols: hydrology, substrate, and vegetation. For optimal results, barrier island and barrier headland/shoreline restoration projects should incorporate vegetative plantings that are focused on at least one of three main habitat types: dune, swale, and back-barrier marsh. Each of these habitats presents unique challenges and environmental stressors that should be addressed if large-scale restoration efforts are to be successful. This section discusses these different habitats and the types of vegetation and techniques that can be employed to increase restoration success.

6.6.2 Dune Habitat

Dune habitats are characterized by extremes of wind-blown sand and salt spray, and soils (sands) with very limited moisture-holding and nutrient-retention ability (Wagner 1964; Hester and Mendelssohn 1991; Mendelssohn et al. 1991). Sediment instability is most extreme in newly deposited sands. Various sand fencing designs can be employed to help maintain the deposited sands within the project area by intercepting wind-blown sand and encouraging dune growth in configurations that run roughly parallel to the coast (Mendelssohn and Hester 1988; Mendelssohn et al. 1991). Sand fencing is available in a variety of materials ranging from traditional wood-slats to plastic meshes and more recently biodegradable natural materials, such as geojute (Mendelssohn and Hester 1988; Miller et al. 2001). The stability provided by sand fencing facilitates more rapid establishment of vegetation adapted to this habitat, which further traps sand and, importantly, binds the sand through extensive root growth.

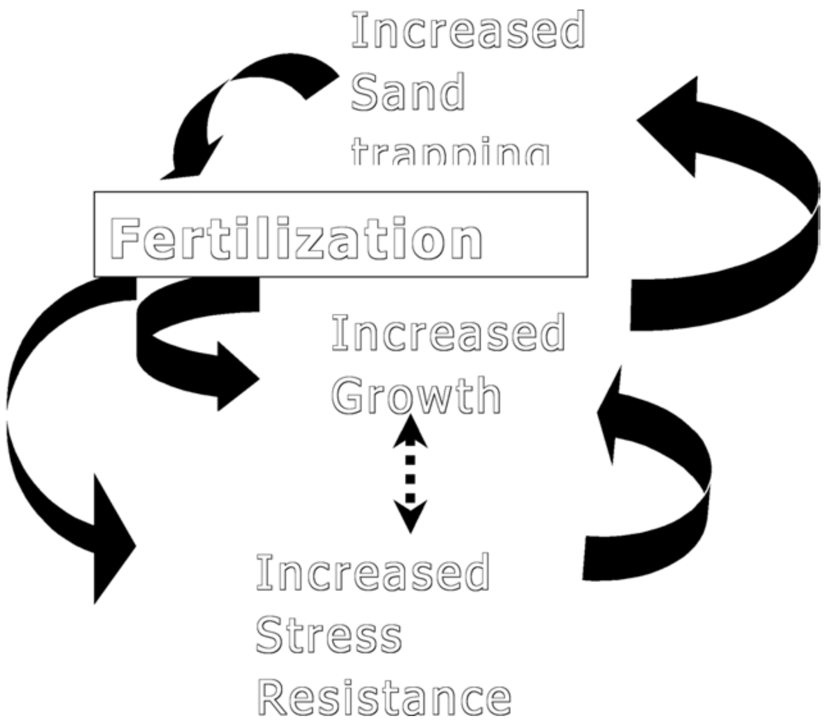
Bitter panicum (*Panicum amarum*) and sea oats (*Uniola paniculata*) are the two most commonly used dune grasses for dune restoration projects throughout the gulf and southeastern Atlantic coasts (Figure D.6- 20; Woodhouse et al. 1982; Mendelssohn and Hester 1988). Both of these species are adapted to low water and nutrient availability, and they produce an extensive shallow and deep root network. Their growth is actually stimulated by being partially buried in wind-blown sand; they derive nutrients from the coating of seawater on the sand grains (Wagner 1964; Hester and Mendelssohn 1989; Hester and Mendelssohn 1991). Seashore paspalum (*Paspalum vaginatum*) is a low-lying grass that can provide excellent coverage in the dune environment once initial sand stability is achieved, although success is often poor if extremes in shifting sands are still present at the site (Mendelssohn and Hester 1988). As depicted in Figure D.6- 21, a fertilization regime can greatly improve vegetation success by creating a positive feedback loop that improves survival and stress resistance, stimulates vigorous growth and spread, and further enhances sand trapping and dune growth.

Restoration efforts in the dune environment can employ mechanical means to sculpt the deposited dredge sands. But this should not be performed until the placed material dewaters. Mechanical placement provides greater initial control in following elevation design templates in supratidal habitats (dune and swale) than may be achieved in the intertidal back-barrier marsh where placed material generally does not as readily support heavy equipment. Similarly, heavy equipment can be utilized to facilitate the planting of the vegetation in both dune and swale habitats at much faster rates than can be achieved by manually planting the transplants (Mendelssohn and Hester 1988; Hester and Mendelssohn 1992).

*Top Panel - Sea oats (*Uniola paniculata*) is an excellent sand-binding grass that has been used extensively in dune restoration projects throughout the southeastern United States (photo courtesy of Mark W. Hester).*

*Bottom Panel - A combination of sand fencing and dune vegetation is critical in trapping and binding sand, thereby stabilizing sand dunes in shoreline restoration projects. In this photograph, bitter panicum (*Panicum amarum*) is seen aggressively colonizing newly deposited sand that has been trapped by the sand fencing. Together, bitter panicum and sea oats are considered the two best dune-building grasses in the southeastern United States (photo courtesy of Mike Materne).*

Figure D.6- 20. Dune-building grasses in the southeastern United States



Fertilization creates a positive feedback loop which stimulates vigorous plant growth. This in turn traps more wind-blown sand, which provides additional growth stimulation via nutrients (largely from salt spray) adhered to the sand grains. An important additional benefit of nutrient augmentation in stressful, nutrient deficient environments is that the additional supply of nitrogen can be used by the vegetation to increase drought and salinity stress resistance through the production of nitrogen-containing compatible solutes. The solutes provide positive feedback to overall plant growth and establishment.

Figure D.6- 21. Conceptual diagram showing the benefits of including a fertilization regime in barrier island vegetative plantings, particularly dune plantings where the sands are extremely nutrient deficient.

6.6.3 Swale Habitat

The swale habitat of barrier islands/headlands is typically a fairly wide area located above the inter-tidal zone between the dune and back-barrier marsh habitats. Plant species diversity is generally highest in this habitat because it is less stressful than either the dune or marsh habitats. The swale habitat offers protection from wind-blown salt spray. In established barrier islands, therefore, the substrate is typically characterized by greater organic matter content and greater moisture and nutrient retention capacity than the more unstable and less developmentally-mature dune sands (Wagner 1964; Mendelssohn and Hester 1988; Snyder and Boss 2002).

Marsh hay cordgrass (*Spartina patens*) is the dominant grass species in the swale. This species tolerates a wide range of water availabilities and salinity levels, and it has a tremendous potential for rapid vegetative expansion (clonal spread), especially in areas where overwash events may remove previously established plant species (Hester et al. 1994; Courtemanche et al. 1999). The establishment of herbaceous cover in the swale environment also facilitates the later establishment of desirable woody species, such as groundsel bush (*Baccharis halimifolia*) and marsh elder (*Iva frutescens*). These species provide important woody structure and habitat for birds and other wildlife (Hester and Mendelssohn 1992).

In large-scale barrier island restoration projects characterized by a wide supratidal zone behind the dune habitat, the utilization of various sand fencing designs can cause more rapid substrate stability, reduce the loss of placed material, and promote more rapid vegetative establishment. The establishment of dense vegetative cover in the swale habitat helps promote island integrity during overwash events by dissipating energy (friction from the aboveground vegetation) and providing substrate stability (from belowground roots).

6.6.4 Back-barrier Marsh Habitat

Proper intertidal elevation is essential for achieving rapid substrate colonization and restoration success in the back-barrier marsh habitat. This presents some unique challenges in terms of accurately estimating settling and compaction rates of the placed dredge material, especially if the material is of a lower sand content (Streever 2000). Nonetheless, numerous smooth cordgrass salt marsh creation and restoration projects have been conducted throughout the Gulf and Atlantic coasts of the U.S., and a tremendous amount of information is available to guide coastal managers in the construction of the successful projects (Streever 2000).

Smooth cordgrass (*Spartina alterniflora*) is the dominant plant species in this habitat. Black mangrove (*Avicennia germinans*) is another important species of the Louisiana back-barrier marsh. This woody species can grow throughout the habitat, but typically establishes at slightly higher elevations than smooth cordgrass (Patterson and Mendelssohn 1991; Mendelssohn and Hester 1988). Along the northern Gulf of Mexico, black mangrove is only present in Louisiana's Deltaic Plain, where temperatures are slightly more favorable for this freeze-intolerant species. Black mangroves are of tremendous wildlife value because of the roosting and nesting habitat that they provide for many shorebirds. Together, smooth cordgrass and black mangrove can form a well-vegetated back-barrier marsh platform that provides important energy dissipation and stability during overwash and barrier island rollover events.

6.6.5 Coastal Plant Technology

Once the physical environment is restored with the appropriate substrate, and the desired elevations are achieved, it is time to revegetate the site. Resource managers must either rely on natural colonization, artificial propagation with local wild plant materials, or artificial propagation with commercially-produced selected plant materials to accomplish vegetative reclamation (Hollis 1992). While wetland restoration designs for the most part attempt to mimic natural wetland processes, newly restored sites begin as highly disturbed, relatively non-productive systems. Natural colonization may occur, but is generally slow and uncertain. A patchy mixture of plant species may result while other areas may remain bare (Landin 1988). Since establishment of plants through natural succession is often unpredictable and accompanied by heavy soil loss, supplemental plant cover by transplanting favors rapid establishment of uniform stands of desirable species. Choices must be made between obtaining plants from commercial nurseries or from the wild. There are advantages and disadvantages to both approaches; both have proponents, and both have their share of detractors (Seliskar 1995).

Some advantages of wild planting stock include:

- Freshly collected wild planting stock generally costs less on a per unit basis.
- Plants collected from the wild are more closely adapted to local environmental conditions than nursery-acquired plants.
- Wild planting stock can be collected and transplanted with limited storage.
- If a diverse natural ecosystem is desirable, natural populations can supply that diversity.
- Some disadvantages of wild planting stock include:
- Undesirable weedy species may be inadvertently included, or rare/endangered species impacted.
- Logistics or difficult collecting conditions may increase the cost of planting material.
- Plants may not be available because of limited supply, growing season, local regulations, or accessibility to private lands.

The degree of genetic differentiation among plant populations and associated implications for survival of planted sites are unknown.

A number of wetland plant species possess high levels of intraspecific variation to important environmental stressors. Those genotypes will maintain their phenotypic differences when grown on common gardens. It is possible to take advantage of these intraspecific genotypic differences, since they provide program managers with a series of options from which to select when designing wetland restoration projects. Plant scientists can develop wetland plant varieties using the tools of ecology, agriculture, and biotechnology to speed the development of man-made marshes to functional equivalency or superiority to natural wetlands (Seliskar 1995).

The USDA Natural Resources Conservation Service (NRCS) and the Louisiana State University Agricultural Center (AgCenter) have been working cooperatively on coastal plant issues and restoration technology for about 10 years. Plant biotechnology and genetic improvement methods are proven and well established in crop production, but have also been applied on a limited basis for bioremediation and coastal wetlands reclamation. The goals of this cooperative program are to: (1) develop and expand the knowledge base and strategies for wetland plant genetic improvement; (2) develop plant materials and restoration techniques for the economic and rapid establishment of critically important wetland plant species; and, (3) develop technology that will facilitate the vegetative establishment of large areas of restored/created coastal wetlands.

One area of particular interest involves reducing the restoration industry's dependence on clonal-based materials and instead developing seed-based plant materials and seeding technology. Program accomplishments have produced protocols for embryo development, tissue culture plant regeneration, and artificial seed (micropropagation). The group has a long-term recurrent selection breeding program in place and has evaluated several thousand plant lines. It is anticipated that four to six improved seed producing cultivars will be released in the next two years. In addition to seed and whole plant research, other on-going studies include bulk seed harvest, storage, dormancy and seed recalcitrance.

By far one of the most active agencies in plant material evaluations and releases has been the Natural Resources Conservation Service through its Plant Materials Program. The Golden Meadow Plant Materials Center is the only federal facility dedicated to coastal wetland plant research. Since 1989, the Golden Meadow Plant Materials Center has released a number of selected and source identified cultivars: *Spartina alterniflora* cv. Vermilion (smooth cordgrass), *Avicennia germinans* cv. Pelican (black mangrove), *Paspalum vaginatum* cv. Brazoria (seashore Paspalum), *Panicum amarum var amarum* cv. Fourchon (bitter Panicum), and *Uniola paniculata* cv. Caminada (sea oats). With the exception of *Avicennia germinans*, all of the released material is clonally propagated and maintained at the Plant Materials Center. Materials released through NRCS's Plant Materials Program are available at no-cost to commercial wetland plant producers for expansion and distribution. Both NRCS and the AgCenter are activity involved in developing rapid and cost efficient planting techniques. Aerial seeding, mechanical planting, hydro-mulching, and fragment plantings are examples of on-going planting studies.

6.6.6 Formula for Vegetation Restoration Success

For the vegetation component of coastal restoration project to be successful, a number of factors need to be considered during the planning, design, and implementation phases of a project:

- Incorporate plant habitat requirements in the project design from the start.
- Create the correct physical environment, particularly in terms of sediment type and elevation for the desired plant communities.
- Correct elevation is crucial in establishing vegetative cover in intertidal marshes.
- Stabilize dune creation sites with sand fencing prior to planting.
- Select key/dominant plant species with desirable traits suited to that habitat.
- Utilize available technology.
- Incorporate a fertilization regime for optimal rapid establishment, survival, and spread.
- Work with nature: plan on secondary species colonizing and adding to species pool.
- Anticipate physical disturbances, such as overwash events. Design the vegetation regime with these events in mind.

By following these guidelines for vegetation restoration success, healthy vegetative cover can be established in barrier island and shoreline restoration projects. The vegetation will facilitate natural colonization and community diversity and, will greatly improve island and shoreline stability during storm events (see Figure D.6- 22).

Top Left Panel – Sea rocket (Cakile fusiformis) is one of the few pioneer plant species that can survive and trap sand in the beach habitat as seen here on Timbalier Island (photo courtesy of Mark W. Hester).

Top Right Panel - Beach tea (Croton punctatus) is the best woody dune species for sand stabilization and dune building as seen here along the Caminda-Moreau coast, an erosional headland (photo courtesy of Mark W. Hester).

Bottom Left Panel - Black mangrove (Avicennia germinans) is an important woody plant species of back-barrier marshes that provides both sediment stability and critical bird nesting habitat (photo courtesy of Mike Materne).

Bottom right Panel - Smooth cordgrass (Spartina alterniflora) displays vigorous growth and spread when correctly planted within the intertidal range of back-barrier marsh creation sites as seen here on Grand Terre Island (photo courtesy of Mike Materne).

Figure D.6-22 Plant species used in barrier island restoration